Performance Assessment of an Onboard Monitoring System for Commercial Motor Vehicle Drivers: A Field Operational Test

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

November 2016

FOREWORD

The Federal Motor Carrier Safety Administration (FMCSA) initiated the onboard monitoring system (OBMS) field operational test (FOT) to identify the safety benefits of OBMSs. The project was conducted in coordination with the University of Washington (UW), the Virginia Tech Transportation Institute (VTTI), and SmartDrive. This report includes the overview and purpose of the OBMS project, the experimental design and data analysis plan, statistical analyses of collected data, conclusions, and study limitations. Potential implications for policies and future research work are also discussed.

NOTICE

QUALITY ASSURANCE STATEMENT

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FMCSA-RRR-15-019		
4. Title and Subtitle **Performance Assessment of an Onboard Monitoring System for Commercial Motor Vehicle Drivers: A Field Operational Test**		5. Report Date **November 2016** 6. Performing Organization Code
7. Author(s) **Boyle, Linda Ng; Guo, Edith Huizhong; Hammond, Rebecca L.; Hanowski, Richard J; Soccolich, Susan A.**		8. Performing Organization Report No.
9. Performing Organization Name and Address **University of Washington** **Dept. of Industrial & Systems Engineering** **Box 352650, Seattle, WA 98195** **Virginia Tech Transportation Institute** **3500 Transportation Research Plaza** **Blacksburg, VA 24061**		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address **U.S. Department of Transportation** **Federal Motor Carrier Safety Administration** **Office of Analysis, Research, and Technology** **1200 New Jersey Ave. SE** **Washington, DC 20590**		13. Type of Report and Period Covered **Final Report, September 2009 – September 2015** 14. Sponsoring Agency Code **FMCSA**
15. Supplementary Notes **Contracting Officer's Representative: Martin R. Walker**		

16. Abstract

The onboard monitoring system (OBMS) field operational test (FOT) was conducted to determine whether onboard monitoring systems that provide real-time performance feedback to commercial truck and motorcoach drivers could reduce the number of safety-critical events (SCEs) experienced over time and improve drivers' overall safety performance. This report documents the field test experience with four operational fleets (two trucking fleets and two motorcoach fleets), including 156 OBMS-instrumented vehicles and 317 commercial drivers. Fleet-level and driver-level analyses were adopted to examine the research questions on driver performance and safety. In the driver-level approach, binary logit regression and repeated measures analysis of variance (ANOVA) were used to examine the effects of phase, carrier type, and study group on the SCE rate. The fleet-level approach examined the reduction in event rates from baseline to intervention/withdrawal phase using a cumulative binomial distribution. Under most scenarios, findings from both approaches were similar, suggesting that onboard monitoring helped to reduce critical event rates. The effectiveness of onboard monitoring was dependent on the carrier and the coaching received. Drivers' responses to questionnaires were also analyzed to examine changes over time in their attitudes toward onboard monitoring. In general, feedback group drivers were mostly ambivalent (i.e., "neutral") with regard to the usefulness of OBMSs. Control group drivers and safety managers tended to have higher opinions of the systems. An additional analysis, focusing on intervention and pre-intervention phases, was conducted to assess the effect of OBMSs on fleet safety, using crash and mileage data collected from the fleets and negative binomial regression methods. The findings showed that there were significant differences in crash rate estimates for Fleet H across the study phases.

17. Key Words	18. Distribution Statement
Commercial motor vehicle, field operational test, FOT, onboard monitoring system, OBMS, safety-critical event, SCE	**No restrictions**

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**134**	

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SI* (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		Length		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	Acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		Volume (volumes greater than 1,000L shall be shown in m^3)		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		Temperature (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Approximate Conversions from SI Units				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		Length		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
Ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		Temperature (exact degrees)		
°C	Celsius	1.8c+32	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force and Pressure or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009.)

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	Definition
ANOVA	analysis of variance
CDL	commercial driver’s license
CMV	commercial motor vehicle
DAS	data acquisition system
FAST DASH	FMCSA’s Advanced System Testing Utilizing a Data Acquisition System on the Highways
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operational test
g	force of gravity
GPS	global positioning system
GSM	Global System for Mobile Communications
HD	hard drive
HOS	hours of service
IDF	instant driver feedback
mi/h	miles per hour
MVMT	million vehicle miles traveled
NTSB	National Transportation Safety Board
OBMS	onboard monitoring system
SCE	safety critical event
SD	standard deviation
USDOT	U.S. Department of Transportation
UW	University of Washington
VMT	vehicle miles traveled
VTTI	Virginia Tech Transportation Institute
WSS	within group sum of squares

EXECUTIVE SUMMARY

The mission of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce the number and severity of crashes on our Nation's highways. In direct support of its mission, FMSCA initiated an onboard monitoring system (OBMS) field operational test (FOT). The objective of this FOT was to determine whether onboard monitoring could reduce at-risk behavior among commercial drivers and improve driver safety performance. More specifically, the aim of the FOT was to determine if recording and reporting of safety-critical events (SCEs), followed by driver coaching (led by safety managers, using video clips of recorded SCEs as feedback), could enhance safe driving behavior.

This report documents the FOT experience with four operational fleets (two trucking fleets and two motorcoach fleets), including 156 OBMS-instrumented vehicles and 317 commercial drivers. These four fleets—examined in detail in this report—are labeled Fleets A, D, E, and H. Fleets A and H were trucking firms and Fleets D and E were motorcoach companies.

RATIONALE AND BACKGROUND

Providing drivers with feedback about how they are performing in real time has been considered an effective way to enhance drivers' immediate and long-term driving performance. Because feedback can be provided on different timescales, the benefits can differ greatly. A 2008 study demonstrated that "when" a driver receives feedback on his/her performance could be considered on a continuum.(1) Feedback could be segmented into four major timescales: concurrent (in real time), delayed (a few seconds later), retrospective (immediately after a trip is complete), and cumulative (feedback that is accumulated after a series of trips).(2) Simulator research has shown that combining concurrent and retrospective feedback can significantly improve driving performance by decreasing response time to lead-vehicle braking events and increasing the number of glances to the road.(3) A 2007 naturalistic study also examined the effects of combined concurrent and cumulative feedback on teenage drivers, using a device placed in the driver's vehicle and a weekly parental review of SCEs.(4) The results suggested that the combined feedback significantly reduced the number of SCEs for at-risk teen drivers, and that the effect of feedback was sustained even after feedback was discontinued.(5,6) These studies demonstrate the value of using concurrent and cumulative feedback to improve driving performance and reduce overall crash rates.

RESEARCH QUESTIONS

Driver Performance and Safety

The primary goal of an OBMS is to enhance driver performance and safety. OBMSs are employed with the expectation that feedback provided concurrently (via flashing feedback lights in the vehicle) and cumulatively (via coaching by safety managers) will have a positive impact on driver performance. The research questions addressed in this study included the following:

- Does individual driving performance improve over time (e.g., less evidence of hard braking, swerving, and speeding; decreased cell phone use, etc.) with OBMS feedback?

- Does the OBMS (with the feedback program) improve safety (e.g., decrease the number of SCEs)?
- If driving performance improves, does the improvement persist?

To address these questions, the following steps were employed:

- Data for each vehicle and driver were collected over 12 months using OBMSs that were instrumented at the beginning of the study.
- This 12-month period included three study phases:
  - A 1-month baseline.
  - A 9-month intervention.
  - A 2-month withdrawal phase.
- In the two trucking fleets (Fleets A and H), drivers were placed into two study groups—feedback and control. There was no control group in the motorcoach fleets (Fleets D and E).
- SCEs were recorded for all phases, but feedback from the system was provided only during the intervention phase and only for the feedback group. Drivers in the control group did not receive any OBMS feedback.
- Two approaches were adopted: a bottom-up, driver-level approach, and a top-down, fleet-level approach. The driver-level approach considers the multilevel-structure of the recorded data, while the fleet-level approach minimizes the effect of outliers, extreme observations, and datasets with incomplete driver-level information.
- For the driver-level analysis:
  - The numbers of critical events per driver were aggregated by week and phase. An event rate was computed as the number of critical events per driver per 100 hours of service (HOS).
  - Binary logit regression and repeated measures analysis of variance (ANOVA) were used to examine the effects of phase and carrier type on the SCE rate.
  - Summary statistics were provided to gain insights on the effects of coaching in reducing the number of critical events per driver per 100 HOS.
- For the fleet-level analysis:
  - The number of critical events was aggregated by fleet and phase. An event rate was computed as the number of critical events per 100 HOS in that fleet.
  - The change in event rate (percent) compared the intervention and withdrawal phase to the baseline phase.

- A cumulative binomial distribution was used to assess whether event rate significantly increased or decreased after the OBMS and feedback program were put into use.

Attitudes toward Onboard Monitoring

Another study goal was to assess drivers' perceptions of onboard monitoring. If drivers do not understand the information provided by the system, or are unwilling to use the information, then it will be difficult to gain support for system implementation. The research questions related to driver attitudes included the following:

- How do drivers' attitudes toward the OBMS and feedback program change over time?
- What are the fleet safety supervisors' attitudes toward the OBMS?

Control group and feedback group drivers received baseline questionnaires, but because the control group did not receive direct information from the OBMS, only drivers in the feedback group were asked about their attitudes toward the OBMS. Completion of the questionnaire was completely voluntary. To address these questions, the following steps were employed:

- The feedback group was provided with a baseline questionnaire before the start of data collection and 1 month after data collection. A feedback questionnaire was administered at the end of months 2–10 (total of 9 months). A withdrawal questionnaire was administered at the end of month 11 and at the end of the study (total of 2 months).
- The control group was provided with a baseline questionnaire at the end of each month.
- Summary statistics were used to gain insights into the changes in driver attitudes toward the OBMS over time.
- Cluster analysis was used to reveal homogeneous groups of drivers based on their responses to the questionnaires.

Crash Reduction

The goal of this analysis was to assess the effect of onboard monitoring on actual crashes for each fleet. To address these questions, the following steps were taken:

- Crash and mileage data were collected from three fleets (Fleets A, D, and H) for the time period associated with the baseline and intervention phases.
- Claims-only crashes, including curb strikes, mechanical failures, non-vehicle-to-vehicle crashes in a parking lot, non-contact conflicts, backing into a dock, vehicle parked when hit, and vandalism, were identified and excluded from the crash analysis.
- Crash rates per 1 million vehicle miles traveled (MVMT) were compared for each phase, using cumulative binomial distribution. Summary statistics in terms of the crash rates were provided for each fleet and each phase to give insights on how crash rates may change after the implementation of instant feedback and coaching.

STUDY FINDINGS

Key findings from the investigation were as follows:

- There were differences in the effectiveness of onboard monitoring among fleets with respect to driver performance.
- About 95 percent of all recorded events were low-severity events and the remaining 5 percent were classified as high-severity events.
- Speeding accounted for about 80 percent of all events for Fleet A (trucking) and Fleet E (motorcoach). Fleet D (motorcoach) had more events associated with unfastened seatbelts (53 percent), and Fleet H (trucking) had more events associated with distraction (58 percent).
- The changes in event rate for Fleet A were as expected. That is, the event rate decreased in the intervention phase and remained fairly stable through this phase. The event rate then remained low in the withdrawal phase after the interventions were removed.
- The low-severity event rates for Fleet E decreased continually over time, which may have been due to the timely coaching provided by this fleet's safety supervisor.
- The binary logit analyses showed no differences in engagement in dangerous behaviors across study groups and study phases for all fleets and severity events. The only exception was for the high-severity events in Fleet E, where drivers were more likely to engage in dangerous behaviors in the intervention phase.
- The ANOVA showed that drivers already engaged in dangerous behaviors in Fleets A and E had lower event rates for high- and low-severity events in the intervention phase when compared to baseline.
- The ANOVA indicated that in Fleet D, during the intervention phase, the high-severity event rates were lower for drivers who were already engaged in dangerous behaviors when compared to the baseline phase, and no significant differences were observed for Fleet H between the intervention and baseline phases.
- The ANOVA indicated that in Fleets D and H, during the intervention phase, the low-severity event rates were higher for drivers who were already engaged in dangerous behaviors when compared to the baseline phase. This could have been due to a higher rate of seatbelt non-compliance in Fleet D and driver identification issues in Fleet H. For example, after removing events associated with seatbelts in Fleet D, the low-severity event rates in the intervention phase were still slightly higher, but the difference is no longer significant.
- The fleet-level approach showed similar conclusions for Fleets A, D, and E.
- The fleet-level approach showed that there was a significant decrease in event rates for high- and low-severity events in Fleet H in the intervention/withdrawal phase when compared to the baseline phase. Fleet H had difficulty providing timely and consistent driver identification; however, the fleet-level analysis includes these drivers, as the overall results are not impacted by driver identification.

- No significant differences were observed between control and feedback group drivers in Fleet A. For Fleet H, control group drivers had even lower event rates than feedback group drivers. However, there were very few samples in the control group and a probable sampling bias toward better drivers when the control group was selected, which limits the conclusions that can be drawn.
- Timely coaching (i.e., events coached within 1 week) appeared to be very effective in reducing critical event rates for Fleet E. More sporadic coaching in Fleets A, D, and H also worked, but not as efficiently as the timely coaching. When no coaching was provided in the intervention phase (i.e., weeks 5–15 in Fleet H), the event rate slightly increased.
- Summary statistics for the questionnaire suggest that drivers tended to have higher expectations of the OBMS in the pre-study and baseline phases, but began to lower their opinions when the intervention phase started. However, the standard deviation of drivers' responses over time was not very high, ranging from 0.83 to 2.02 on a scale of 1 (strongly disagree) to 7 (strongly agree). That is, there was not much variation in responses over time. For example, a participant who reported "strongly agree" to a survey question in month 1 may have dropped one scale to "agree" in a latter month.
- Feedback group drivers were satisfied with the system, agreeing that it helped them become more aware of their surroundings and made them safer drivers. Those who were not satisfied complained that it distracted them from the road and was not always operational.
- Control group drivers tended to have more positive attitudes toward the OBMS than feedback group drivers.
- Safety managers tended to have relatively consistent attitudes over time. They were also more likely to have higher opinions about the OBMS than the drivers.
- In the analysis of fleet-level crash data, Fleet H showed a statistically significant decrease in crash rate of 59.8 percent with the OBMS (i.e., 12.5 crashes per MVMT in pre-intervention and 5.0 crashes per MVMT in intervention).
- Fleet A did not have a statistically significant change in crash rate.
- A majority of vehicles did not experience a crash (80.3 percent of baseline vehicles and 75.7 percent of intervention vehicles had a crash rate of 0 crashes per MVMT).

CONCLUSIONS

Results from both the summary statistics and the inferential analyses suggest that the OBMS did improve driver performance and safety for the four fleets in most cases. That said, for the driver-level analysis, low severity event rates increased for Fleet D and Fleet H after OBMS feedback was activated in the intervention phase. This could be a consequence of a higher rate of seatbelt non-compliance in Fleet D and the driver identification issue in Fleet H. There were no significant differences observed in event rate between the control and feedback groups. This could be due to the small sample size for the control group, which limits the inferences that can be made. Hence, the finding that individual driving performance can improve over time with OBMS feedback should be considered in light of the study's limitations.

Effectiveness of coaching by safety managers differed by fleets. The fleet with the most timely coaching (i.e., events were coached within 1 week) experienced a notable and continual decrease in the number of critical events per driver per 100 HOS in the intervention phase. Sporadic coaching was less effective in reducing critical event rate. Critical event rate was observed to increase in the one fleet for which almost no coaching was conducted.

Professional drivers and safety supervisors generally had positive opinions about the OBMS. Drivers' opinions about the system tended to go down once the intervention phase began. Despite that, they still felt there were benefits to the system. Fleet safety supervisors had more positive opinions than drivers; their attitudes were very consistent before and after the study.

The analysis was conducted using two methods: at the fleet level, to assess the overall benefits for each fleet; and at the driver level, for identifying factors related to at-risk driver behavior. The fleet level provides a general overview of the effectiveness of the OBMS in enhancing overall safety, but does not provide insights on how best to target at-risk behavior. With respect to crash reduction, the OBMS immediate feedback and coaching had a significant impact for one fleet (Fleet H). However, this analysis was limited to a 9-month pre-intervention and 9-month intervention period. So, it could be that positive effects in the other fleets might be seen in a longer duration study. Regardless, assessing OBMS efficacy using fleet crash data is an important topic to continue investigating. A longer evaluation period is recommended for future studies, as it may reveal more clearly the benefits of the OBMS with respect to crash mitigation.

1. BACKGROUND AND OBJECTIVES

1.1 BACKGROUND

The mission of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce the number and severity of crashes on our Nation's highways.

In 2012, 3,921 people were killed and 104,000 people were injured in crashes involving large trucks. About 18 percent of those killed and 24 percent of those injured in large truck crashes were large truck occupants.(7)

In direct support of its mission, FMSCA initiated an onboard monitoring system (OBMS) field operational test (FOT). The objective of this FOT was to determine whether onboard monitoring could reduce at-risk behavior among commercial drivers and improve driver safety performance. More specifically, the aim of the project was to determine if recording and reporting of safety-critical events (SCEs), followed by driver coaching (led by safety managers, using video clips of recorded SCEs as feedback), could enhance safe driving behavior.

Operator monitoring and feedback can be characterized as a behavior-based safety method.(8) Safe behavior is rewarded and unsafe behavior is coached, thereby proactively improving overall safety. The OBMS used in this study recorded snippets of video and other performance/kinematic measures to target unsafe driving behaviors, and it provided real-time feedback to drivers. Recorded driver problems (e.g., hard braking maneuvers) were then transmitted to and reviewed by the driver's fleet safety manager. Depending on the judgment of the fleet safety manager, the recorded incident was then shown to the driver in a coaching session with the goal of pinpointing the problematic behavior and providing instruction on how to avoid that behavior in the future.

There are a few studies in the literature that have investigated the efficacy of onboard monitoring. For example, FMCSA recently sponsored a study (through FMCSA's Advanced System Testing utilizing a Data Acquisition System on the Highways [FAST DASH] program) to investigate the efficacy of a technology with automated in-cab, real-time verbal coaching when the driver was speeding, driving aggressively, or not wearing a seatbelt. A second study is currently investigating the benefits of an onboard video recording system to reduce risky driving behaviors along with fuel and truck maintenance costs. (9) This project covers a 17-month period (5 months baseline, 6 months of using an OBMS with real-time light indicator [treatment 1]), and 6 months of an OBMS with light indicator and coaching [treatment 2]). Preliminary findings show that participant drivers' severe event rates do significantly decrease in the intervention phase (with coaching) when compared to the baseline.

In addition, previous FMCSA-funded research found significant improvements as measured by a reduction in SCEs when an OBMS program was implemented. (10) However, a limitation of this study was that the observation period was just 13 weeks. The current study looks to build upon that earlier program by utilizing a different OBMS and studying an OBMS program over a longer period of time (12 months).

A recent safety report by the National Transportation Safety Board (NTSB) discussed two crashes where continuous video systems were installed on the vehicles. [11] This report summarized that continuous onboard video systems can be useful tools for crash evaluation and assessing crash survivability, by providing valuable information such as kinematics data of occupants involved in the collision and critical vehicle dynamics. The report also pointed out that improper camera positions and lack of low-light recording capabilities may result in inadequate capture of information.

1.1.1 Research Team

Under the original contract for this study, Transecurity, LLC served as the OBMS technology vendor. After approximately 2 years of study time, Transecurity, LLC became unviable and subsequently withdrew their participation from the study. Under the direction of FMCSA, the research team approached SmartDrive Systems and requested their participation as an alternate OBMS technology vendor. While Transecurity, LLC served as the OBMS technology vendor, a total of 45 vehicles were instrumented with study equipment; however, not enough data were collected from those vehicles to conduct meaningful analyses. The remainder of this report includes detailed information pertaining to the data collected with SmartDrive Systems' OBMS (i.e., the SmartRecorder).

Figure 1 shows the team structure that was used during the remainder of the study. Phase I involved the collection of epoch data from the OBMS and an evaluation of this data by the University of Washington. Phase II involved the collection of naturalistic data from the Virginia Tech Transportation Institute (VTTI) data acquisition system (DAS) to provide continuous data for future analysis efforts.

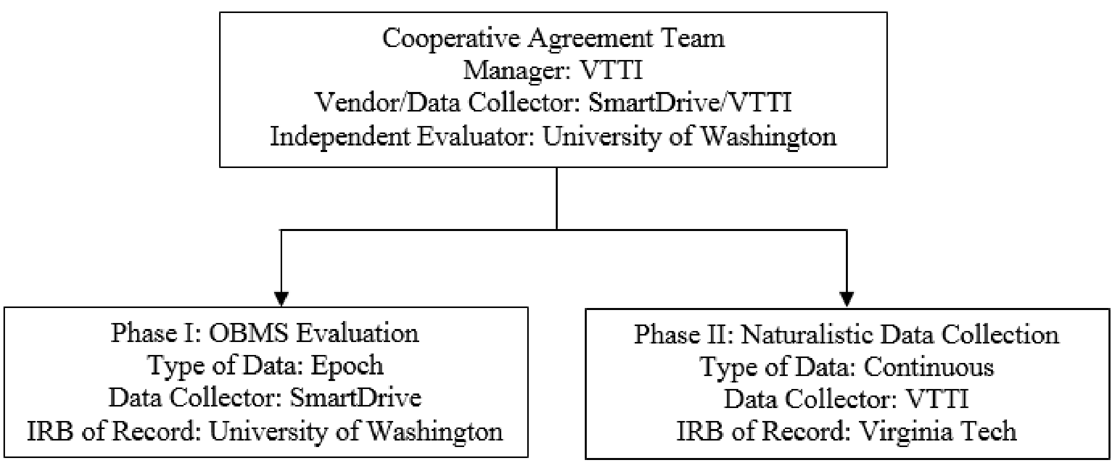

Figure 1. Diagram. Overview of the cooperative agreement and study structure.

1.2 STUDY OBJECTIVES

While the main purpose of this study was to determine if OBMS use provides a safety benefit to fleets and reduces the number of SCEs experienced over time, researchers also explored changes in drivers' and safety managers' attitudes toward onboard monitoring.

1.2.1 Driver Performance and Safety

OBMSs are employed with the expectation that feedback provided concurrently (via flashing feedback lights in the vehicle) and cumulatively (via coaching by safety managers) will have a positive impact on driver performance. It is possible to observe this positive impact by viewing the video epoch data[i] recorded by the OBMS. However, epoch data may not always be interpreted correctly without observing the driving situation. Thus, continuous naturalistic driving data (with video) were also recorded by the DAS during the study and were available as needed to validate the findings of the epoch data. The research questions related to driver performance and safety included the following:

- Does individual driving performance improve over time (e.g., less evidence of hard braking, swerving, and speeding; decreased cell phone use, etc.) with OBMS feedback?
- Does the OBMS (with coaching) improve safety (e.g., decrease the number of SCEs)?
- If driving performance improves, does the improvement persist?

1.2.2 Attitudes toward the OBMS

Use of an OBMS may be affected by users' perceptions of the system; hence, the following attitude-related research questions were included:

- How do participating drivers' attitudes toward the OBMS and feedback program change over time?
- What are the participating fleet safety supervisors' attitudes toward the OBMS?

1.2.3 Crash Reduction

The goal of this analysis was to assess the effect of the OBMS and feedback program on actual crashes for each fleet. There was one research question included:

- Does the OBMS (with coaching) significantly lower crash rates?

[i] For the current study, a video epoch recorded by the OBMS was 30 seconds long (15 seconds before the trigger threshold was exceeded and 15 seconds after the trigger threshold was exceeded). The OBMS used in this study was always recording but not always saving, so when an event was triggered, the system has a buffered recording and was able to save the 15 seconds prior to the trigger and the 15 seconds after.

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2. METHODS

2.1 EXPERIMENTAL DESIGN

The evaluation focused on determining if the feedback from the OBMS reduced the number of SCEs experienced by drivers over the course of the study. It is important to note that driver behavior could have improved or worsened during the study period for several reasons that may be unrelated to the OBMS. Some potential factors include greater familiarity with the system and with the fleet operation due to increased exposure, which may naturally improve driving over time. There might also be a Hawthorne effect, which is defined as the phenomenon of a study participant's behavior changing simply because he or she is being studied.(12) Such changes have nothing to do with the intervention and do not provide a lasting benefit. To avoid these potential confounders, the research team compared the OBMS feedback group with a small control group of vehicles/drivers. Not all fleets were included in this control group; it was possible to include only 2 fleets with a total of 14 controls. The data collection period for the feedback group was broken down as follows:

- Baseline: 1 month (approximately).
- Intervention/feedback: 9 months.
- Withdrawal: 2 months.

During the 1-month baseline period, participants drove an instrumented vehicle with an OBMS that recorded events but did not provide driver feedback, and drivers did not receive coaching from their safety managers. When the intervention period started, drivers began receiving immediate feedback from the OBMS. During this period, drivers attended coaching sessions with their safety managers. Safety managers were not given instruction on coaching methods or frequency, and they scheduled coaching sessions as they determined appropriate. After the feedback period, the system reverted to a no-feedback (i.e., withdrawal) period for the remaining 2 months of the study.

The study hypothesis was that drivers in the feedback group would have fewer SCEs than drivers in the control group. If the hypothesis holds true for feedback group drivers, there are two potential outcomes of extended OBMS use:

- Potential Outcome 1: Compared to baseline, drivers have fewer SCEs in both the intervention and withdrawal phases. This could mean improvements in drivers' habits and behaviors with extended OBMS use and the persistence of these improvements even after the feedback is removed (i.e., the system trains the driver).
- Potential Outcome 2: Compared to baseline, drivers have fewer SCEs in the intervention phase, but not necessarily in the withdrawal phase. This outcome reflects the ability of the system to help drivers recover from momentary lapses in driving performance (i.e., by providing warning alerts). However, the effects may not persist. That is, the overall benefits/outcomes may not be as pronounced because drivers do not continue to receive

immediate feedback on potential SCEs, nor do they receive the warning alerts (see Figure 2).

It is recognized that there may be some spillover effects from the control group (Group 1) to the feedback group (Group 2), particularly if the drivers are all at the same terminal sites. In addition to heightened awareness of risks, control group drivers may also inadvertently receive coaching.

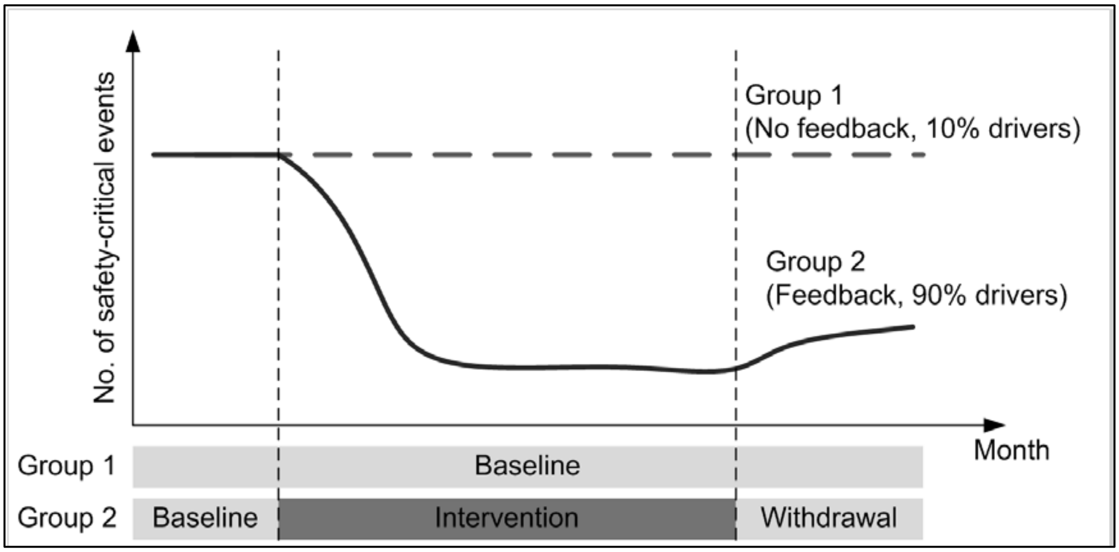

Figure 2. Diagram. Experimental design and expected result.

2.1.1 Questionnaire Design

2.1.1.1 Feedback (Coached) Group

Drivers in the feedback group received a baseline questionnaire (Appendix A) prior to the start of data collection (during the recruitment process) and after month 1 of data collection. They also received a feedback questionnaire at the end of months 2–10 (Appendix B) and a withdrawal questionnaire (Appendix C) at the end of month 11 and at the end of the study (month 12).

2.1.1.2 Control Group

Thirteen questionnaires were provided to the control group. All 13 questionnaires were identical and had the same questions as the baseline questionnaire given to the feedback group during recruitment and at the end of month 1. Questionnaires for control group drivers and feedback group drivers were administered at the same time for consistency.

2.1.1.3 Safety Managers

Safety managers also received two questionnaires. The baseline questionnaire (Appendix D) was administered during the recruitment process to assess managers' perceptions of the system. The post-intervention questionnaire (Appendix E) was administered at the end of the study to assess whether the safety managers felt the system effectively provided feedback to the drivers. The questionnaire distribution timeline for the feedback and control groups and the safety managers is shown in Table 1.

Table 1. Questionnaire distribution timeline.

Group	Before data collection	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
Feedback	BL	BL	FB	FB	FB	FB	FB	FB	FB	FB	FB	WD	WD
Control	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL
Safety Managers	Pre	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Post

Note: BL=baseline, FB=feedback, and W=withdrawal.

2.2 APPARATUS

2.2.1 Onboard Monitoring System

This project evaluated a commercially available OBMS. The OBMS used in the study combined video, audio, and vehicle data and was triggered by sudden vehicle movements, such as swerving and hard braking. A speed sensor connected to the engine computer also identified speeding violations. The specific hardware included in the OBMS is described below.

2.2.1.1 Onboard Monitoring System Hardware Overview

Figure 3 shows the OBMS hardware, with an insert describing the major components. Two cameras were positioned to record the forward roadway and the driver's face. For this study, the head-unit was mounted on the windshield with the cameras mounted together, as shown in Figure 4.

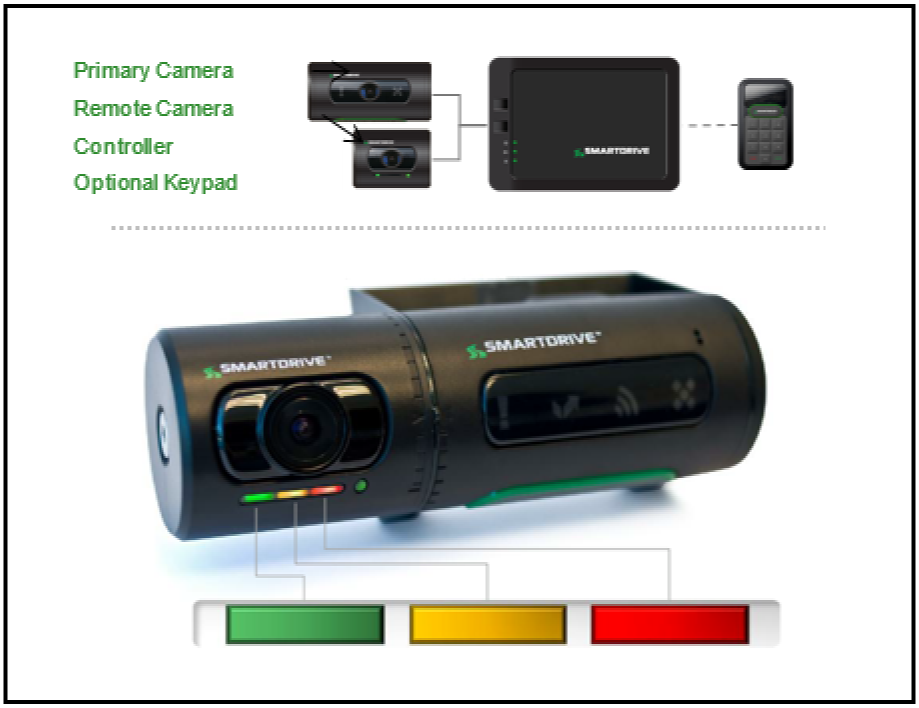

Figure 3. Photo. OBMS head-unit.

Figure 4. Photo. Example of vehicle with the two cameras mounted separately.

The system was configured to meet specific requirements of the study that were outside of the standard operating configuration relative to instant driver feedback (IDF). The IDF lights (i.e., green, yellow, and red lights on the driver-facing camera) provided drivers with instant feedback on their driving maneuvers. When an unsafe maneuver was detected, a yellow or red light (based on the severity of the maneuver) flashed for a few seconds. During each trip, a solid green, yellow, or red light indicated the driver's safety score. The solid green light indicated most safe, and red indicated least safe. The driver's goal was to maintain a green light for the entire trip.

Before implementation of the system, handbooks with pictures and descriptions of the system were distributed to participating drivers. No other forms of training were provided; therefore, it is possible that some drivers may have been confused about the system's operation. However, judging by comments in the questionnaire, most drivers had no difficulty understanding the system.

A detailed list of the specific technologies, sensors, and outputs is provided below.

- Core technologies:
  - DM6446 Digital Video Evaluation Module (ARM9 and DSP).
  - Four gigabyte (GB) memory.
  - Global System for Mobile Communication (GSM) or Code Division Multiple Access (CDMA) cellular/mobile service network.
  - 802.11 b/g/n Wi-Fi.
  - Two cameras.
  - Engine control unit (ECU) (J1939, J1708, Onboard Diagnostic System [OBD II]).

  - Global positioning system (GPS).
  - Universal serial bus (USB).
  - Rechargeable battery.
  - Infrared illuminators.
- Sensors and inputs:
  - Video (752 x 480 resolution at 4 frames per second).
  - Audio.
  - Location.
  - Speed.
  - Acceleration (triple axis [3g] and 96g accelerometers; g = force of gravity).
  - Third-party triggering inputs.
  - Keypad and manual activation button.
- Physical outputs:
  - Instant driver feedback.
  - Speaker.
  - Display.
  - Hard disk/flash drive.
  - Alerts and notifications.

2.2.1.2 Onboard Monitoring System Functionality and Process Overview

The OBMS used in the study determined when to record video events using advanced, proprietary triggering algorithms that leveraged sensor inputs from a variety of sources. While the OBMS continuously recorded data, it did not continuously save it. When an algorithm was triggered by a risky driving event (e.g., hard braking, speeding, or swerving), the OBMS had a buffered recording and was able to save the 15 seconds prior to the trigger and the 15 seconds after the trigger. Once an event was captured, it was offloaded to a central review center through the GSM wireless network, then analyzed and classified by driving data analysts.

As shown in Figure 5, the OBMS recorded events using triggering algorithms that leveraged:

- Dual multi-axis accelerometers:
  - A triple axis (3g) accelerometer, which measures movements such as swerving and hard braking.
  - A 96g crash sensor, which identifies certain types of collisions that cannot be efficiently detected by a 3g accelerometer alone.
- A speed sensor, which determines when the vehicle exceeds a safe speed.

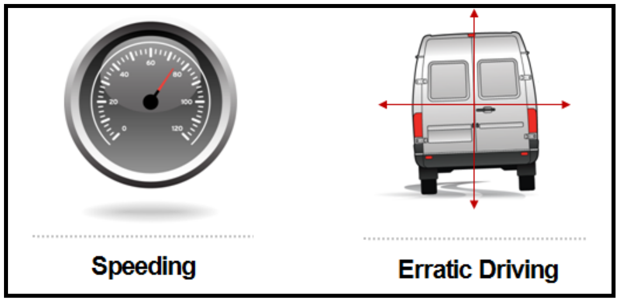

Figure 5. Diagram. Example triggers for capturing events.

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Data analysts reviewed the recorded segments to validate them. Recorded events consisted of video, audio, speed, acceleration, location, and other driver and vehicle information. Spurious events (e.g., driver hit a pothole in the road) were identified as not safety-related.

Once events were analyzed, fleet safety managers were able to access them via a Web-based application. Events that matched predefined criteria were automatically queued for coaching. Drivers received their personalized coaching through the OBMS event player, shown in Figure 6. Safety managers were able to choose which events to coach, and the OBMS event player replayed video events captured by the OBMS and incorporated critical behavioral, driving, vehicle, and environmental data for a full view of what happened and why.

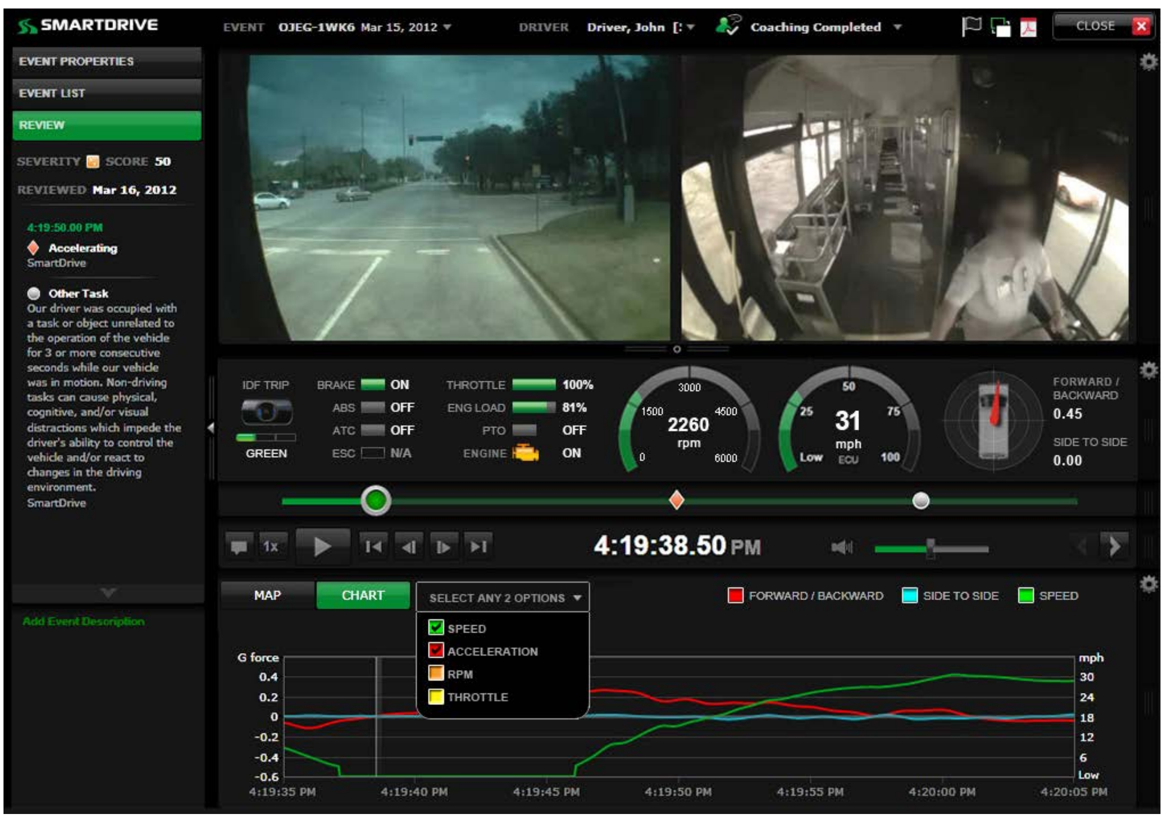

Figure 6. Image. A screenshot of the OBMS event player.

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2.2.2 Data Acquisition System

The research institution that managed this study has spent more than a decade pioneering the naturalistic approach for studying transportation safety issues related to light vehicles,[13] commercial vehicles,[14,15] police vehicles,[16] and most recently, motorcycles.[17] All of these previous studies were successful in revealing the underlying contributing factors to vehicle crashes and helping shape or redefine important transportation safety policies. The results of these previous studies have influenced national transportation policy in several areas, including commercial driver hours of service (HOS) and cell phone usage.[18,19,20] As in previous studies, this study employed naturalistic data collection methods to obtain naturalistic data and record crashes and near-crashes in real-world operating conditions.

For many years, the research institution conducting this study designed and refined data acquisition technologies for safety system evaluations. In the current study, the research team utilized the NextGen DAS (shown in Figure 7), which employs a Linux operating system and captures three general groups of measures:

- DAS measures.
- Vehicle network measures.
- Add-on measures.

During the 12-month evaluation period for this study, the DAS collected all three groups of data. Data were collected by the DAS from the time the vehicle's ignition was turned on to the time its ignition was turned off. Data were saved continuously throughout the data collection period. Periodically, the DAS data were retrieved from vehicles by the research team's onsite personnel. The DAS was installed independently of the OBMS and had no connection with that system.

Figure 7. Photo. NextGen DAS.

The general design characteristics for the NextGen DAS are described below:

- Compatible with the vehicle (e.g., power obtained from vehicle battery, data from in-vehicle network).
- Unobtrusive and non-invasive:
  - Not distracting.
  - Does not limit driver visibility.
  - No permanent modifications to the vehicle.
  - Minimal space requirement for data storage unit.
  - Automatic start-up, shut-down, and continuous operation.
  - No subject tasks required for operation or data downloading.
- Reliable performance in the often-harsh operational driving environment; minimal data loss and automatic detection of failures.
- Continuous multi-camera video recording system (15 hertz [Hz]) to capture driver's face, over-the-shoulder, wide-angle rearward, and forward scenes.
- Ruggedness and crash survivability.

The NextGen DAS provides a flexible and maintainable hardware data collection system. It is unobtrusively installed in vehicles to facilitate naturalistic driving behavior during controlled driving on the Virginia Smart Road test track or in naturalistic on-road settings. As shown in Figure 8, the DAS instrumentation is concealed from the driver as much as possible. For example, cameras are mounted behind mirrors, while wires and other data recording equipment are hidden under interior panels.

Figure 8. Photo. DAS mounted in the glove box of a motorcoach.

The DAS used in this study can be rapidly installed/de-installed, and every effort was made to leave each vehicle as close to its original condition as possible. The hardware and software design teams were mindful to minimize participant inconvenience and to reduce in-vehicle space requirements. All of the microprocessor boards, including the firmware and data collection software, were developed by the researcher.

The DAS used in this study was designed to add other sensors and data items as required for a particular project. It has the capability to utilize precision technologies such as GPS and universal medium range radar for position and ranging measurement. Vehicle-based data collection systems record multi-channel H.264 compressed video/audio on a custom electronics package designed specifically for automotive/truck use. Color, black-and-white, and infrared video cameras record external views (e.g., forward and rearward) and internal views (e.g., over-the-shoulder capturing the vehicle instrumentation panel and driver hand position, face with eye glance, etc.). Other non-video time-series data collected can include items such as turn signal use, illumination, position/distance, speed, lateral and longitudinal *g*-forces, and yaw rate. The specific measures on any given vehicle may not be identical, as they are based on available J1939 bus data for each vehicle and this data can vary from one vehicle to another. However, Appendix F provides an example of the types of data that are typically collected. The next section details the specific data elements collected in this study.

2.2.2.1 Data Acquisition System Sensors

GPS: A GPS device (included in the DAS) was used primarily for tracking the instrumented vehicles and placing them in time and space. Data output included measures of latitude, longitude, altitude, horizontal and vertical velocity, heading, and status/strength of satellite acquisition.

Lane Tracker: The lane tracker included in the NextGen DAS is a custom machine-vision process that grabs video frames from the forward camera feed. Note that the “grabbed” video frames are not stored but are processed algorithmically in real time to calculate the vehicle position relative to road lane markings. The lane tracker can be configured to operate at 10 Hz in real time while the data are being collected. The following variables were reported by the lane tracker technology:

- Distance from center of car to left and right lane markings (estimated max error less than 6 inches and average error less than 2 inches).
- Angular offset between car centerline and road centerline (estimated max error less than 1 degree).
- Approximate road curvature.
- Confidence in reported values for each marking found.
- Marking characteristics, such as dashed line versus solid line and double line versus single line.
- Status information, such as in-lane or solid line crossed.

Once installed, the lane tracker software automatically calibrates to determine camera position; thus, no elaborate calibration procedure was required for this study.

Yaw Rate: Three yaw rate (gyro) sensors are included in the DAS. These sensors provided a measure of steering instability (e.g., jerky steering movements).

X/Y/Z Accelerometer: Accelerometers installed in the vehicle were used to measure longitudinal (x), lateral (y), and vertical (z) accelerations.

Vehicle Network: The measures that can be accessed from a particular vehicle depend on the make, model, and year of the vehicle. As such, it is possible that certain measures are only available for certain instrumented vehicles. The available measures are defined in a header file in each data set. The portion of the data set that includes the vehicle network data typically contains measures of the following:

- Vehicle speed.
- Odometer.
- Ignition signal.
- Throttle position.
- Brake pressure.

Outside of the available vehicle network measures, other driver input measures that can be collected with sensors include the following:

- Right and left turn signals.
- Brake pressure (if not available from the network).

Note that the DAS did not provide any feedback to the driver. The data collected from the DAS were for research purposes only and could be analyzed only when off-loaded from the vehicle.

As noted, this study represents a comprehensive efficacy study of the tested commercial driver OBMS. Installation and data collection began in February 2013 and finished in November 2014. The remainder of this section describes the recruitment and data collection processes.

2.3 EXPERIMENTAL PROCEDURES

2.3.1 Fleet Recruitment

A goal of this study was to include a diverse selection of fleets, both by location and by operation. As shown in Figure 9, eight different fleets participated in the study for varying amounts of time. Table 2 shows a breakdown of participating fleets by location and operation.

Figure 9. Map. Location of participating fleets and number of vehicles installed.

Table 2. Participating fleets by location and operation.

Fleet	Location	Operation
A	Baton Rouge, LA	Grocery—Reefer
B	Escanaba, MI	Dry goods – various operations including long-haul, regional; company and owner-operator drivers
C	Selma, NC	Fuel-tanker
D	Los Angeles, CA	Motorcoach
E	San Antonio, TX	Motorcoach
F	Coraopolis, PA	Oil Field
G	Williamsport, PA	Oil Field
H	Pembroke, NH	Grocery—Reefer

Fleets that agreed to participate in the study received 12 months of OBMS service. Fleets were offered compensation for vehicles taken out of service for equipment installation and de-installation. Once fleets agreed to participate, research team representatives traveled to each location to recruit drivers. This process is described in more detail below.

Four out of the eight fleets (Fleets A, D, E and H) completed the full 12 months of data collection. The other four fleets dropped out mainly due to operational issues or clients' privacy/security concerns regarding cameras.

2.3.2 Onboard Monitoring System and Data Acquisition System Installation and Participant Recruitment

OBMSs and DASs were installed in all vehicles at every location except Pembroke, NH and Tampa, FL. The Pembroke, NH location was the last to sign up for the study and there were no more DASs available, but each vehicle was outfitted with an OBMS. The Tampa, FL location was one of the first to participate and 45 vehicles were installed with a DAS; however, the installed OBMS came from a different vendor (as noted in Section 1), and the data collected from those vehicles could not be included in the final analysis. Table 3 shows how many vehicles had a DAS installed during the course of the study.

Table 3. Number of OBMS and DAS units installed at each fleet.

Fleet	Location	Installation Date	Consented Drivers*	Vehicles Installed with an OBMS	Vehicles Installed with a DAS
A	Baton Rouge, LA	February 2013	58	66	66
B	Escanaba, MI	March 2013	15	15	15
C	Selma, NC	April 2013	50	36	36
D	Los Angeles, CA	May 2013	38	23	23
E	San Antonio, TX	June 2013	27	20	20
F	Coraopolis, PA	August 2013	5	10	10
G	Williamsport, PA	August 2013	21	12	12
H	Pembroke, NH	October 2013	18	47	18
		Total	**232**	**229**	**200**

*Drivers only had to consent for the DAS data collection. Participating carriers already had OBMS data collection policies, so all drivers "participated" in the OBMS piece.

Participants were recruited at the same time equipment was installed. Table 3 also shows how many drivers from each fleet signed up to participate. At the time of recruitment, researchers met with drivers to explain the study and ask if they were interested in participating. Drivers who were interested then signed an informed consent form (as shown in Appendix G for truck drivers and Appendix H for motorcoach drivers), and filled out a demographics questionnaire (see Appendix I) and the first OBMS questionnaire (shown in Appendix A). Drivers were paid $100 for agreeing to sign up, and an additional $50 for completing the questionnaires. Approximately 80 percent of drivers who were approached by the research team, across all fleets, agreed to participate.

2.3.3 Data Collection and Retrieval

The OBMS data, including video clips, were uploaded wirelessly to the OBMS data review center. Each video was reviewed and coded based on the driver's behaviors according to a standardized process and risk scoring criteria.

The success of the naturalistic data collection effort was dependent on an efficient process for transferring data from the DASs to a secure storage medium at the research facility for future analyses. Figure 10 provides a process flow by which the naturalistic driving data were collected from the fleets and transferred to the researcher's data storage center on long-term storage tapes.

At each of the test sites, a subcontracted onsite technician retrieved the DAS hard drives (HDs) from the instrumented trucks and distributed the monthly questionnaires. Throughout the course of the study, it was determined that this method did not work reliably and by the end of the study, onsite technicians were eliminated, and research team employees were sent to the sites as needed.

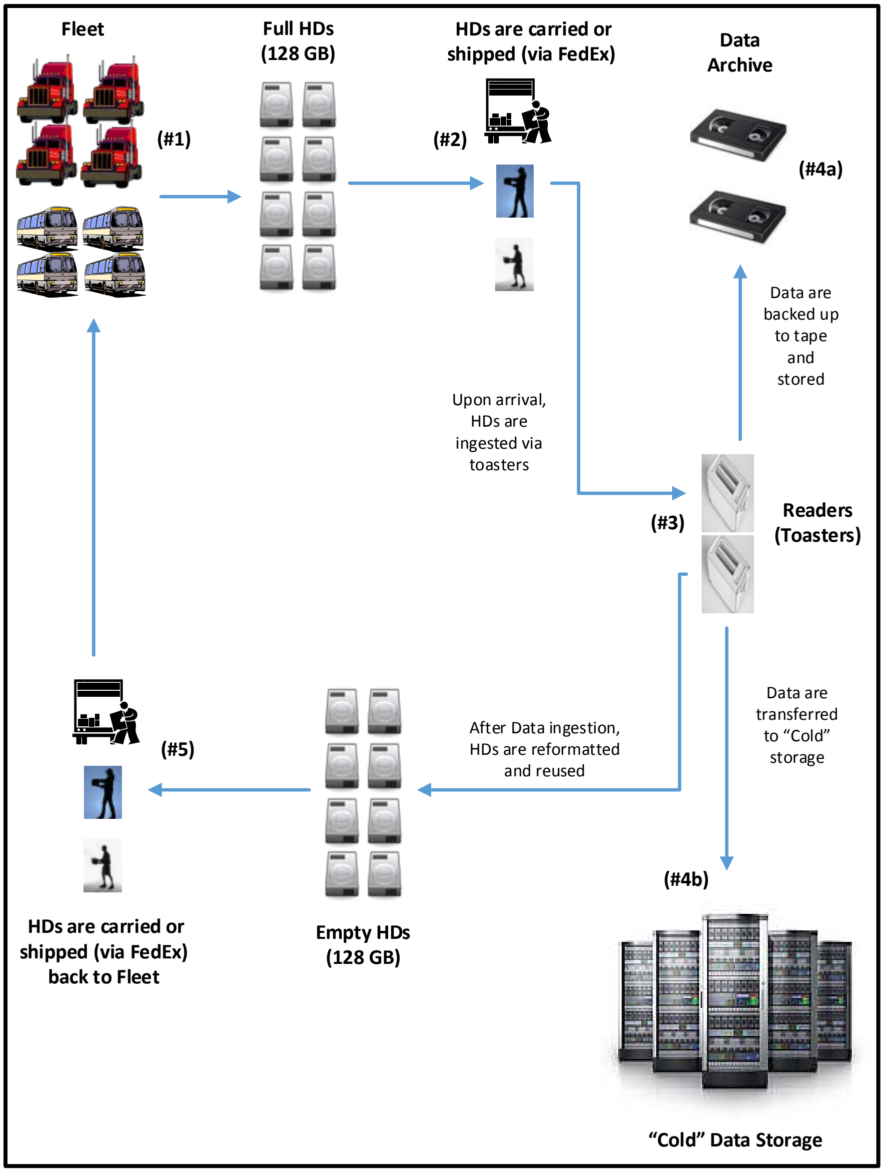


Figure 10. Diagram. Flow chart of the naturalistic driving data collection flow.

As the DAS HDs were removed from the vehicles (see Figure 10, #1), the technician documented the HD's serial number along with the date the HD was retrieved from the truck. The HD was then hand-carried or shipped to the research team (see Figure 10, #2) for data download.

Researchers unpacked the external HDs, inspected the condition of each, and documented in the database each HD's serial number and the date the external HD was received. Then, the researcher downloaded the raw data from the DAS HDs through two proprietary HD readers connected to an onsite computer server (see Figure 10, #3). Each HD reader could process four HDs simultaneously. These downloaded data were then stored on a server at the research facility. To ensure data integrity, the server would hold a copy of the files until the transfer to more permanent storage at the research facility was confirmed. This commercial-off-the-shelf platform provided efficient, cost-effective, temporary in-house storage. Once the files were confirmed to be stored on the server, researchers cleared the memory from the external HDs. Finally, the files were transferred to large tape drives at the research team's data storage facility (see Figure 10, #4a) and the research team's cold data storage facility (see Figure 10, #4b) for future analyses.

The empty external HDs were then sent back to the fleet locations and documented (see Figure 10, #5) in the database by each HD's serial number and the date the HD was sent back to the fleet locations. This entire process was repeated throughout the data collection period.

2.3.4 Post–data Collection Procedures

Once data collection ended, the researchers traveled to each fleet to de-install the equipment. During this visit, all equipment was removed from each vehicle and shipped back to the research team. Researchers also met with participating drivers at this time to complete the final paperwork and distribute final payment. Drivers were asked to complete the withdrawal questionnaire (see Appendix C), the post-study questionnaire (shown in Appendix J for the feedback group, and Appendix K for the control group) and the training and education form (Appendix L). Drivers also received their final payment of $300 for completing the study.

3. RESULTS

As noted in Section 2.3.1, eight different fleets participated in the study; four of them finished the full 12 months of data collection. The number of critical events and critical event rates were compared across different study phases (baseline, intervention, and withdrawal) and different study groups (feedback and control). Results and conclusions presented in this section are based on analysis of the four fleets that completed the study over the 12-month period. The analysis was conducted across all fleets and within each fleet.

3.1 DATA AND ANALYSES

Specific variables used for the analyses include:

- Phase:
  - Baseline.
  - Intervention.
  - Withdrawal.
- Group:
  - Control.
  - Feedback.
- Fleet: This includes only those carriers that completed the entire 12 months of data collection: Fleets A, D, E, and H (out of eight fleets).
- Event severity level: These are based on the SCEs and are recorded for non-collision events ranging from 1–4, with 4 being the highest.
- Number of events: A count of all recorded events per driver.
- SCEs: These are events (excluding collisions) for the top five behaviors: distraction, seatbelt use, speeding, stopping, fatigue (and “other”). These were chosen for inclusion out of 70 possible categories defined by the OBMS; 21 categories of behavior were observed during this study (see Table 7).
- HOS: HOS are based on the number of hours the driver was in service during a shift. It should be noted that a difference was observed for the HOS computation given two methods of data retrieval.
  - *Method 1*: From the mileage data: the calculated maximum HOS per driver per day was about 14 hours.
  - *Method 2*: From the driver-schedule data: the maximum could be as high as 23 hours.

  The HOS computed from the mileage data appeared more reasonable and was used to compute the event rate.
- Questionnaire data: Obtained from the demographic questionnaire and pre- and post-intervention questionnaires for drivers and safety supervisors.

- Effectiveness of the system (real-time and cumulative feedback).
- Usability of the system (real-time and cumulative feedback).
- Effectiveness of coaching.
- Preferences and attitudes.

The research questions related to driver performance and safety were examined using a bottom-up, driver-level approach and a top-down, fleet-level approach. In the bottom up, driver-level approach (which will be referred to as driver-level for the remainder of the report), event count and HOS were examined by driver and week. The effectiveness of the OBMS was examined using event rate as the dependent variable (in the driver-level analysis), which was calculated as the number of events per driver per 100 hours of driving.

Summary and inferential statistics for driver-level analyses were used to examine the research questions. Mean event rate by high- and low-severity level—as well as by different groups and fleets—were computed, with trends shown graphically. Mean event rates associated with the most frequently observed behaviors were also analyzed separately.

When aggregated by driver as well as by group and study phase, the critical event rate was highly skewed due to the large numbers of zeros (which means the specific driver had no critical events captured by the OBMS during that phase) and severely violated the normality assumption of the forthcoming repeated measures analysis of variance (ANOVA), even after transformation. Therefore, a binary logit model was first applied to examine relationships between group/phase and the occurrence of zeros (critical event rate = 0). In this context, this model predicts the likelihood of a specific driver to engage in dangerous behaviors given his/her group and the study phase. A repeated measures ANOVA was further applied to nonzero response (critical event rate ≠ 0), which aims to detect any differences in event rate among phases and groups.

Separate repeated measures ANOVAs were used to examine differences in high- and low-severity rates over different time periods. In this study, the driver event rate was measured over several study phases. As shown in Figure 11, an example model can be represented as:

$$\frac{\#\ of\ high\ severity\ events\ for\ driver_{ij}}{HOS\ for\ driver_{ij}} = \mu + Phase_{ij} + Fleet_i + Group_i + \epsilon_{ij}$$

Figure 11. Equation. Example model for measuring driver event rate.

where μ is the population mean value;
$Phase_{ij}$ represents the study phase j of either baseline, intervention, or withdrawal phase for driver i;
$Fleet_i$ and $Group_i$ indicate which fleet and group driver i belongs to; and
ε_{ij} is the error term for the unexplained variations for driver i in phase j associated with the experiment.

HOS per driver, calculated in terms of a 100-HOS scale, was the exposure method used. Given the 1-year study span, with different start times, study phases were considered separately as within-subject factors, while “fleet” and “group” were the between-subject factors.

In the top down, fleet-level approach (which will be referred to as fleet-level for the remainder of this report), event count and HOS were examined by fleet and study phase for high- and low-severity events. Event rate (events per 100 HOS) of fleet i in study phase j can be represented as:

$$Event\ Rate_{ij} = \frac{Total\ number\ of\ events\ happened\ in\ study\ phase\ j}{Total\ HOS\ in\ study\ phase\ j} \times 100$$

Figure 12. Equation. Calculation of fleet event rate by study phase.

A relative change in event rates from the intervention/withdrawal phase to the baseline phase was calculated and tested using the null hypothesis that the likelihood of the event in the baseline phase does not differ from the likelihood of the event in the intervention/withdrawal phase. The likelihood of obtaining a result equal to or more than the observed number of events during the baseline phase was computed using the cumulative distribution function of binomial distribution, where the expected probability of assignment for each study period equals the fraction of total exposure associated with that period. A calculated likelihood (*p*-value) less than $\alpha = 0.05$ suggests that the number of events that happened in the baseline phase was likely not random. That is, after implementing the OBMS in this study, the relative change compared to the baseline is significant.

The data examined has a multi-level structure. There are multiple recorded events per driver, there are within-subject variations within each treatment phase, and the number of hours driven is different for each driver. These individual variations denote the importance of a driver-level analysis. It is recognized that at this level, the analysis is more sensitive to outliers and extreme values when compared to a fleet-level approach. A fleet-level approach includes all events irrespective of any driver identification. This level provides an overall assessment of the fleet.

3.2 DRIVER PERFORMANCE AND SAFETY

3.2.1 Driver-level Approach: Summary Statistics

Fleets A, D, E, and H completed all 12 months of data collection. The number of drivers in the control and feedback groups is shown in Table 4.

Table 4. Number of drivers by group.

Group and Phase	Fleet A (Trucking)	Fleet H (Trucking)	Fleet D (Motorcoach)	Fleet E (Motorcoach)
Feedback – Baseline	71	53	48	29
Feedback – Intervention	85	72	98	36
Feedback – Withdrawal	72	57	N/A	4*
Feedback Total	**88**	**74**	**102**	**40**
Control – Baseline	8	3	N/A	N/A
Control – Intervention	10	4	N/A	N/A
Control – Withdrawal	8	4	N/A	N/A
Control Total	**10**	**4**	**N/A**	**N/A**

*Only four drivers in the feedback group in Fleet E can be recognized during the withdrawal phase; other drivers are identified as “unknown” drivers. There was no feedback provided to drivers in the control group. The phase denotes the timeframe only for when drivers were in the study.

Table 5 shows the data that were provided for each fleet. Fleets A and H operated commercial trucks, and Fleets D and E operated motorcoaches. Therefore, analysis of the effectiveness of the OBMS in commercial trucks focuses on driver performance in Fleets A and H, and analysis of the effectiveness of the OBMS in motorcoaches focuses on driver performance in Fleets D and E.

It should be noted that Fleet D did not have a withdrawal phase, and Fleet E did not have HOS data for the withdrawal phase; thus, it was not possible to calculate the critical event rate of the withdrawal phase for these two fleets.

Table 5. Data availability by fleet.

Data Type/ Phase/Group	Fleet A (trucking)	Fleet H (trucking)	Fleet D (motorcoach)	Fleet E (motorcoach)
Event data	03/04/2013 (start) 03/03/2014 (end)	11/01/2013 (start) 10/31/2014 (end)	06/12/2013 (start) 06/11/2014 (end)	07/15/2013 (start) 07/14/2014 (end)
HOS data	03/04/2013 (start) 03/03/2014 (end)	11/01/2013 (start) 10/31/2014 (end)	06/12–12/22/2013; 02/21–06/11/2014	07/15/2013–03/26/2014; 05/09–05/12/2014
Baseline Phase	A	A	A	A
Intervention Phase	A	A	A	A
Withdrawal Phase	A	A	NA	A
Control Group	A	A	NA	NA
Feedback Group	A	A	A	A

Note: A=Available; NA=Not Available.

3.2.1.1 Event Severity Level

Table 6 shows the total number of critical events for all four severity levels by fleet, with 1 being the lowest and 4 being the highest severity level. This table includes only data from identifiable drivers (i.e., there are no unknown driver data). For Fleets A, D, and E, level 1 severity events account for about 80 percent of all events, and level 2 severity events account for about 15 percent. Only 3–5 percent of all events are associated with severity levels 3 or 4. Nevertheless, Fleet H has considerably fewer severity level 1 and 2 events, and more severity level 3 and 4 events. This might be due to the fact that the thresholds for each severity level were customizable by the fleet manager. Fleets A, D, and E used the default setting for these thresholds, but Fleet H re-categorized eight low-severity events to high-severity events.

Table 6. Total number of critical events by severity for four fleets.

Severity Level	Fleet A (number)	Fleet A (percent)	Fleet H (number)	Fleet H (percent)	Fleet D (number)	Fleet D (percent)	Fleet E (number)	Fleet E (percent)
1	24,594	83%	5,153	48%	16,154	80%	6,441	79%
2	4,271	14%	3,409	32%	3,230	16%	1,299	16%
3	639	2%	1,051	10%	458	2%	312	4%
4	244	1%	1,201	11%	385	2%	126	2%
Total	**29,748**	**N/A**	**10,814**	**N/A**	**20,227**	**N/A**	**8,178**	**N/A**

The mean event rate per driver by severity level and fleet is shown in Figure 13.

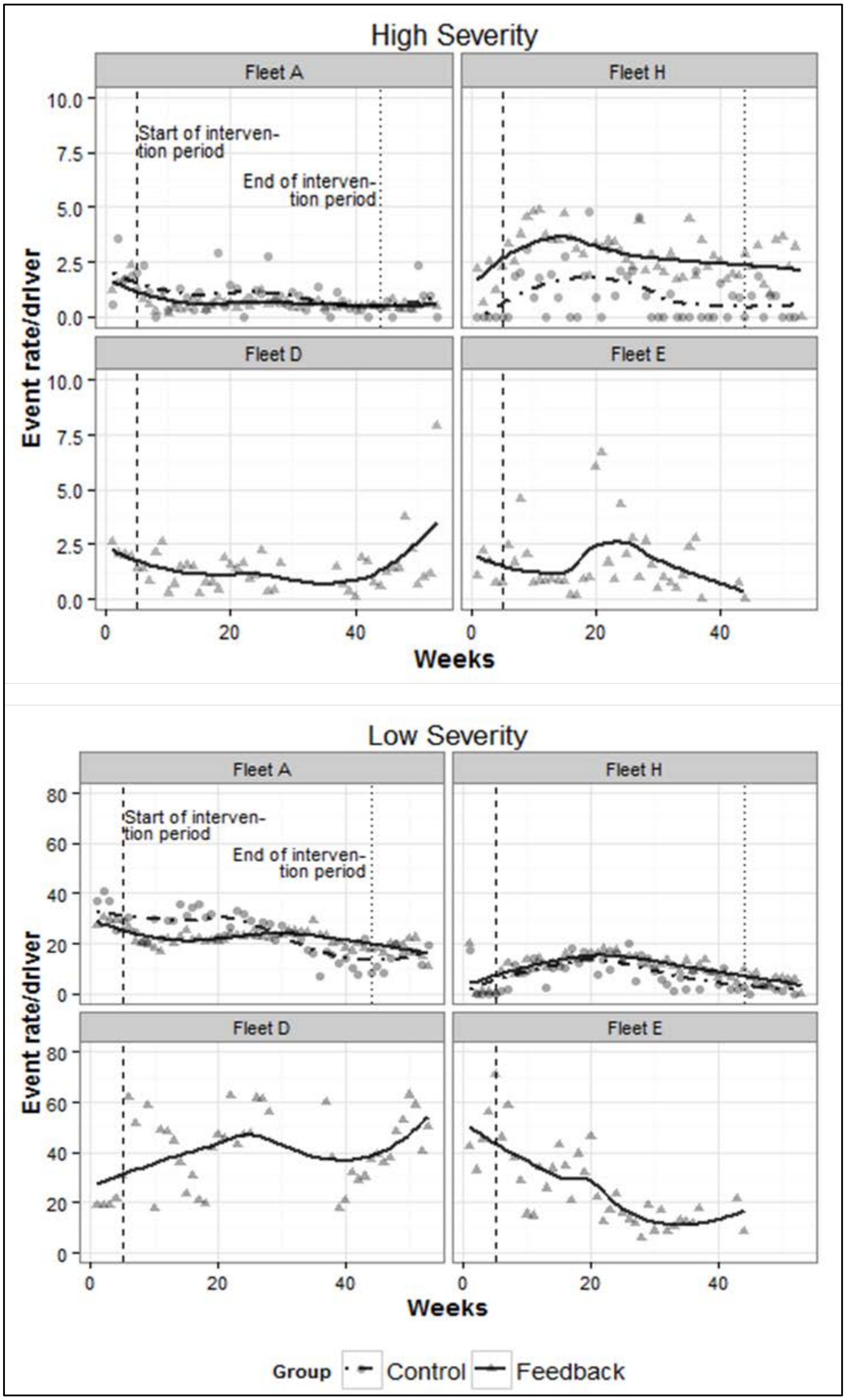


Figure 13. Graph. Mean event rate per driver per 100 HOS by fleet.

Figure 13 provides an indicator of driver performance over time for each fleet and level of severity. One important point is that the effectiveness of the OBMS was greatly dependent on the fleet. There were also some technical issues with the OBMS (for three of the four fleets) and this might have also impacted the outcomes. (These issues are discussed in greater detail in this and the following section.) Observations related to drivers' event rates by level of severity (by fleet) are discussed below:

For high-severity events:

- The high-severity event rate for Fleet A decreased at the beginning of the intervention phase and stabilized afterwards. The feedback group in this fleet had a slightly lower rate than the control group.
- For Fleet H, the control and feedback groups shared a similar trend. However, the performance for the feedback group in this fleet was worse than the control group.
- The rate for Fleet D fluctuated over the intervention phase and increased toward the end of the study.
- The rate for Fleet E decreased at the beginning of the intervention phase, and then experienced a surge of events around the 20th week.

For low-severity events:

- The low-severity event rate was higher than the high-severity rate.
- The rate for Fleet A decreased at the beginning of the intervention phase and stabilized afterwards. Although the control group had a higher event rate until the 30th week, it performed better than the feedback group after that.
- The event rate for the two groups in Fleet H showed similar trends. The rate increased until the 20th week but decreased after that.
- The low-severity event rate for Fleet D fluctuated and no stable trend can be observed.
- The rate for Fleet E continually deceased during the intervention phase.

3.2.1.2 Behavioral Categories

Critical events were automatically grouped into 21 behavioral categories by the OBMS (as shown in Table 7). As noted earlier, the top five categories (speeding, seatbelt unfastened, distraction, fatigue, and stopping) accounted for 96 percent of all observed events. These five categories were also the most frequently observed for Fleets A, E, and H. For Fleet D, "Smart Recorder" is the third most observed behavior. Smart Recorder is a category that includes events associated with "suboptimal camera position" and "non-performing camera." Neither of these is typically defined as a dangerous driving behavior with respect to traffic safety performance. Therefore, the forthcoming analysis includes only the aforementioned five behavioral categories: speeding, seatbelt unfastened, distraction, fatigue, and (improper) stopping.

Table 7. Number of SCEs (and percent) by behavior categories.

Rank	Behavior Category	Total	Fleet A (trucking)	Fleet H (trucking)	Fleet D (motorcoach)	Fleet E (motorcoach)
1	**Speeding**	40,522	24,129 **(81%)**	1,682 (14%)	7,585 (32%)	**7,126 (78%)**
2	**Seatbelt Unfastened**	17,498	3,210 (11%)	1,411 (12%)	**12,304 (53%)**	573 (6%)
3	**Distraction**	12,767	4,358 (15%)	**7,019 (58%)**	560 (2%)	830 (9%)
4	**Fatigue**	2,797	1,479 (5%)	612 (5%)	397 (2%)	309 (3%)
5	**Stopping**	1,948	501 (2%)	847 (7%)	396 (2%)	204 (2%)
6	**Smart Recorder**	1,830	20 (0%)	49 (0%)	1,761 (8%)	0 (0%)
7	**Obstructed View**	568	284 (1%)	103 (1%)	180 (1%)	1 (0%)
8	**Situational Awareness**	467	40 (0%)	267 (2%)	66 (0%)	94 (1%)
9	**Unprofessional Driving**	370	105 (0%)	95 (1%)	120 (1%)	50 (1%)
10	**Vehicle Control**	114	64 (0%)	46 (0%)	2 (0%)	2 (0%)
11	**Unprofessional Conduct**	28	13 (0%)	13 (0%)	2 (0%)	0 (0%)
12	**Near Collision**	13	1 (0%)	7 (0%)	4 (0%)	1 (0%)
13	**Tampering**	2	2 (0%)	0 (0%)	0 (0%)	0 (0%)
14	**Event of Interest**	1	0 (0%)	1 (0%)	0 (0%)	0 (0%)
15	**Collision**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
16	**Hand Position**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
17	**Inattention**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
18	**Keypad Usage**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
19	**Smart Recorder Usage**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
20	**Unsafe and Improper**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
21	**Other Outcomes**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)
22	**Unknown**	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)

Speeding

The speeding behavior category included three types of observations:

- Moderate speeding (≤10 miles per hour (mi/h) over the posted speed limit).
- Excessive speeding (>10 mi/h over the posted speed limit).
- Exceeding maximum speed set by fleet.

For Fleets A, D, and E, approximately 90 percent of the speeding events were associated with "exceeding maximum speed set by fleet." For these three fleets, about 5–8 percent of the events were associated with moderate speeding and 1–6 percent of the events were associated with excessive speeding. On the other hand, for Fleet H, 71 percent of the speeding events were associated with moderate speeding, 13 percent with excessive speeding, and only 16 percent with exceed maximum fleet speed.

Seatbelt Unfastened

As for events categorized as "seatbelt unfastened," for Fleets A, D, and H, about 80 percent of the events were identified as "driver seatbelt unfastened (vehicle speed ≤ 20 mi/h)," whereas for

Fleet E, about 80 percent of the events were identified as “driver seatbelt unfastened (vehicle speed >20 mi/h).” It should be noted that Fleet D experienced an extremely large number of events associated with the seatbelt-unfastened category (10,573 seatbelt-unfastened events in Fleet D, compared to 2,443 in Fleet A, 128 in Fleet E, and 1,134 in Fleet H). This larger number could have been related to technical issues with detecting seatbelts at lower speeds, compounded with other issues such as seasonal or temporary drivers, route stops at airport arrival or departure terminals, etc.

Distraction

The distraction category included 11 types of observations:

- Mobile phone—texting/dialing.
- Mobile phone—talking (handheld).
- Mobile phone—talking (hands free).
- Operating other mobile devices.
- Reading paperwork.
- Grooming/personal hygiene.
- Food.
- Beverage.
- Smoking.
- Passenger(s).
- Other tasks.

For Fleet A, 31 percent of the captured distraction events were associated with food and 29 percent were associated with beverage. For Fleet D, 26 percent of the distraction events were associated with other tasks, 16 percent were associated with beverage, and 13 percent were associated with food. Distraction events captured for Fleet E were most likely to be identified as hands-free mobile phone talking (26 percent), beverage (23 percent), or food (20 percent). For Fleet H, 40 percent of the distraction events were identified as hands- free mobile phone talking, 20 percent were identified as smoking, 12 percent as food, and 13 percent as beverage.

Fatigue

The fatigue category included “drowsy/falling asleep” and “yawning.” For all four fleets, more than 99 percent of the recorded fatigue events were associated with yawning. For Fleet A, just four events were identified as drowsy/falling asleep; Fleets E and H each had only one drowsy/falling asleep event.

Stopping

The stopping category included seven types of observations, three of which were not recorded by the system during this study. Among the other four observation types, drivers were most likely to stop incompletely at light (Fleet A—27 percent; Fleet D—16 percent; Fleet E—9 percent; and Fleet H—4 percent) or at a stop sign (Fleet A—52 percent; Fleet D—81 percent; Fleet E—88 percent; and Fleet H—84 percent). This category also included “failing to attempt to stop at light” (Fleet A—20 percent, Fleet D—2 percent, Fleet E—1 percent and Fleet H—3 percent) and “failing to attempt to stop at a stop sign” (Fleet A—1 percent, Fleet D—1 percent, Fleet E—1 percent and Fleet H—8 percent).

Other Behavioral Categories

The other categories that were recorded by the system during this study include the following:

- Events containing errors relating to the OBMS equipment were identified as:
  - Smart Recorder.
  - Obstructed view.
  - Tempering.
- Events involving errors of fundamental driving were categorized by the vendor as:
  - Unprofessional driving (i.e., unsafe braking, unsafe lane change/merging/passing, driving the wrong way, etc.).
  - Vehicle control (i.e., driving with two hands off wheel or unattended moving vehicles).
  - Situational awareness (i.e., unsafe following, not checking mirrors, not scanning road ahead, or not scanning intersection).

Event Rates by Behavioral Category

Figure 14 shows the mean event rates per driver associated with fatigue, stopping, seatbelt unfastened, speeding, and distraction.

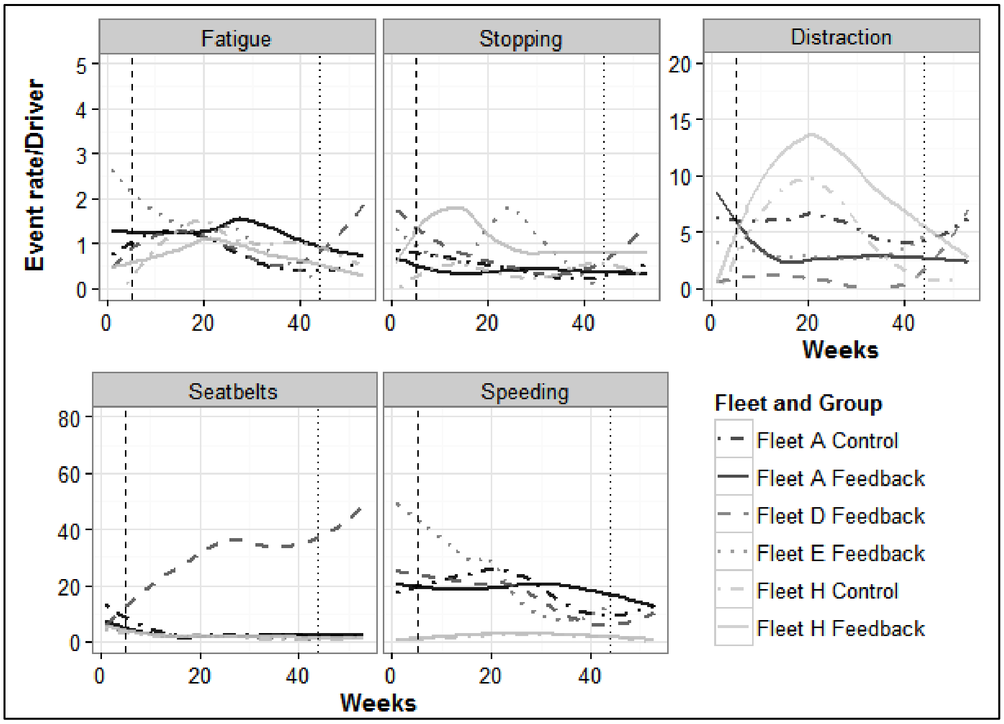


Figure 14. Graph. Mean event rate of the five most frequently observed behaviors.

The fatigue event rate for Fleet E continually decreased, but for all other fleets, fatigue events initially increased until around week 20 and decreased thereafter. For Fleet D, the rate increased again during the last 2 months of the study; this phenomenon was observed for other behaviors, as well.

The improper stopping event rate for Fleet E first increased until week 15 and decreased to a stable level afterwards. For the feedback group in Fleet H, the improper stopping rate decreased when the intervention began, but then rapidly increased until week 25. After that, the event rate decreased again.

The seatbelt unfastened and speeding event rates were much higher compared to the fatigue and stopping event rates. For unfastened-seatbelt events, the rate increased over time for Fleet D. The speeding event rate for Fleets A, D, and E all decreased over time, and this rate for Fleet H remained low throughout the entire study period.

The distraction event rate for Fleet H increased until week 20; this rate for the feedback group was also higher than the control group. The distraction event rate for the feedback group in Fleet A decreased notably with the application of intervention and stabilized after that. For other fleets, the distraction event rate was relatively stable throughout the study period.

3.2.1.3 Age Group

Analysis was conducted to compare driver safety performance between age groups. It should be noted that driver age was reported in the questionnaire; therefore, this information was only available for drivers who participated in the questionnaire. More specifically, six control group drivers (75 percent) from Fleet A and one control group driver (25 percent) from Fleet H reported their age. The breakdown of feedback group drivers who reported their age in the questionnaire is as follows:

- Fleet A: 52 drivers (62 percent) reported their age.
- Fleet H: 17 drivers (23 percent) reported their age.
- Fleet D: 32 drivers (31 percent) reported their age.
- Fleet E: 27 drivers (73 percent) reported their age.

Figure 15 shows drivers' age distribution by fleet. It seems that the age distribution in each fleet was quite similar, with Fleet E tending to have a greater number of older drivers than middle-aged drivers. However, it is not clear if this is a consequence of the potential bias in sampling.

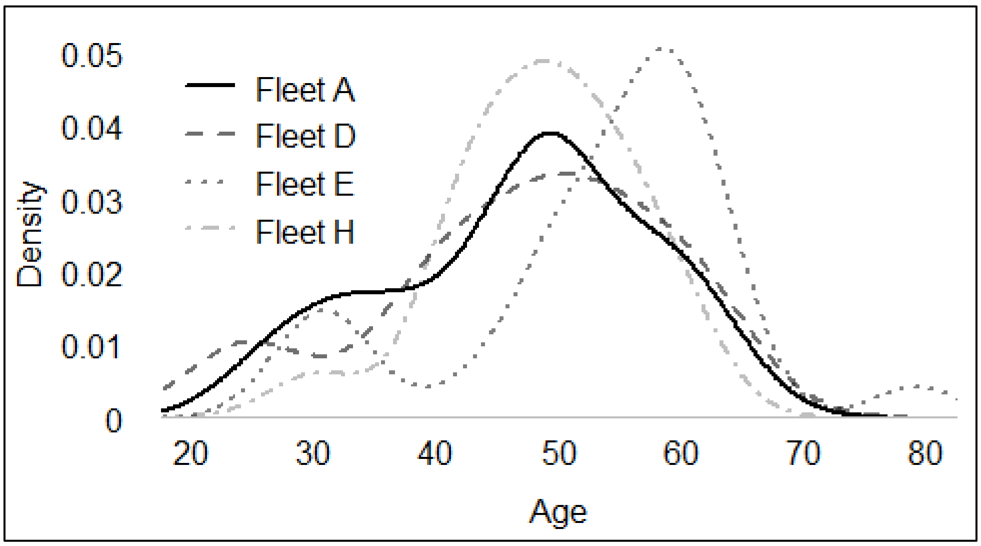


Figure 15. Graph. Density plot of age by fleet.

Event Rates by Age Group

Mean high- and low-severity event rates by fleet and age group are shown in Figure 16. For Fleets A and E, event rates of the three age groups had similar patterns, suggesting drivers in different age groups performed and reacted to the OBMS similarly in those two fleets. For Fleet D, the high-severity event rate of young drivers (less than 40 years old) had more variations than that of middle-aged (41–60 years old) and older drivers (more than 60 years old). The low-severity event rate of young drivers in Fleet D was higher than the low-severity event rates of middle-aged and older drivers until around week 38, and was lower after week 40. Young drivers in this fleet reacted most quickly to the feedback; however, their performance was less stable than drivers in the other two age groups. For Fleet H, high-severity event rates for young drivers were lower than the high-severity event rates for middle-aged drivers until week 20, and the low-severity event rate of young drivers was always higher.

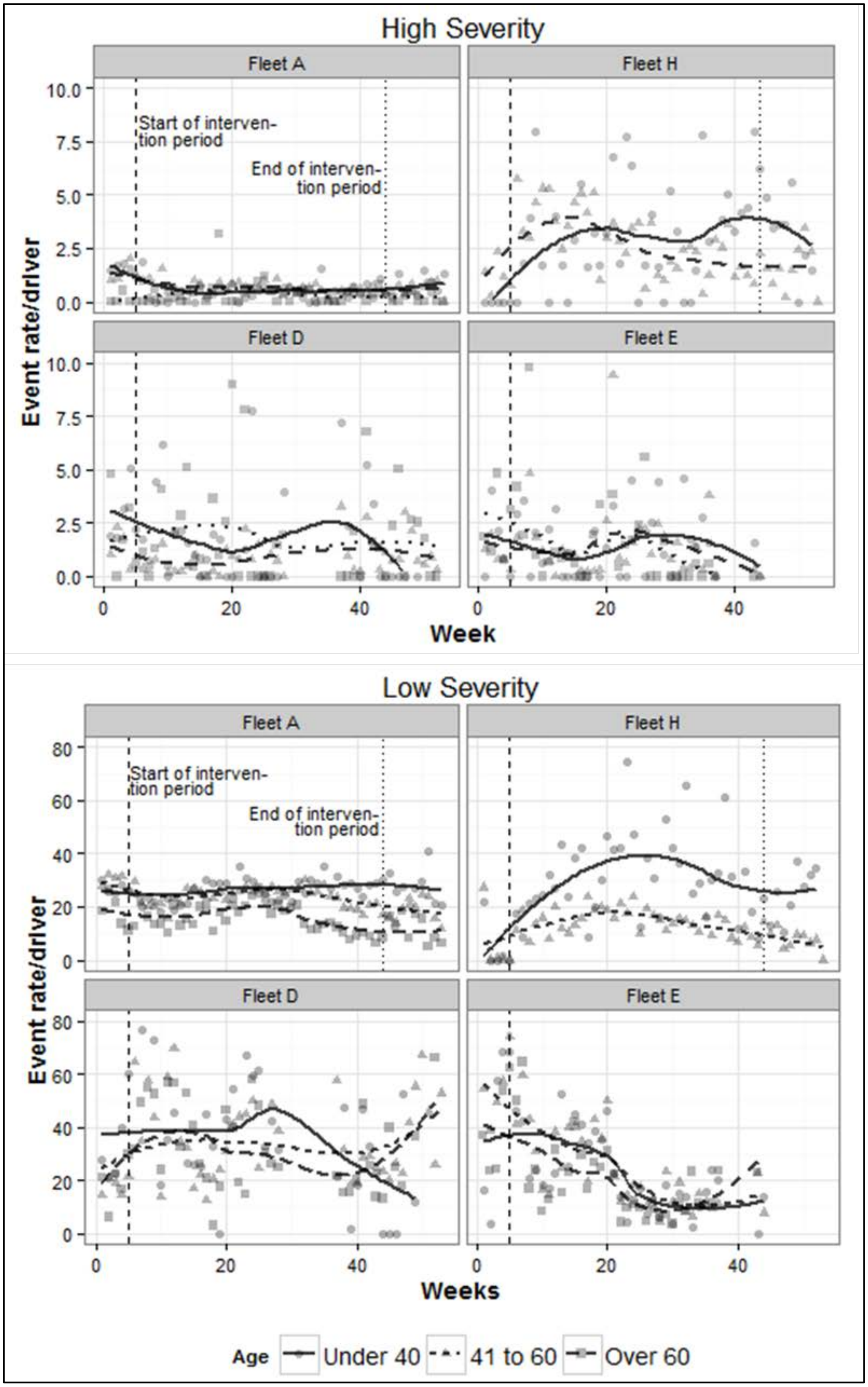


Figure 16. Graph. Mean event rate per driver per 100 HOS by fleet and age group.

Figure 17 shows the mean event rate by age groups based on merged data from all four fleets. For high-severity events, the event rate for young drivers dropped quickly at the beginning of the study, which may indicate that they reacted most quickly to the OBMS feedback. The event rate for older drivers was lower than the event rates for young and middle-aged drivers after week 20, while young and middle-aged drivers performed similarly. For low-severity events, the event rates for drivers in all three age groups showed similar patterns over the study period: the event rates were relatively stable in the first 2–3 months and slowly decreased during the intervention phase. However, for middle-aged drivers, the event rate increased again toward the end of the study, which may have resulted from the increase in the event rate for middle-aged drivers in Fleet D. In general, young drivers always had a higher event rate, which indicates worse safety performance than middle-aged and older drivers. Middle-aged and older drivers performed similarly until around week 10, and older drivers always had better safety performance after this point.

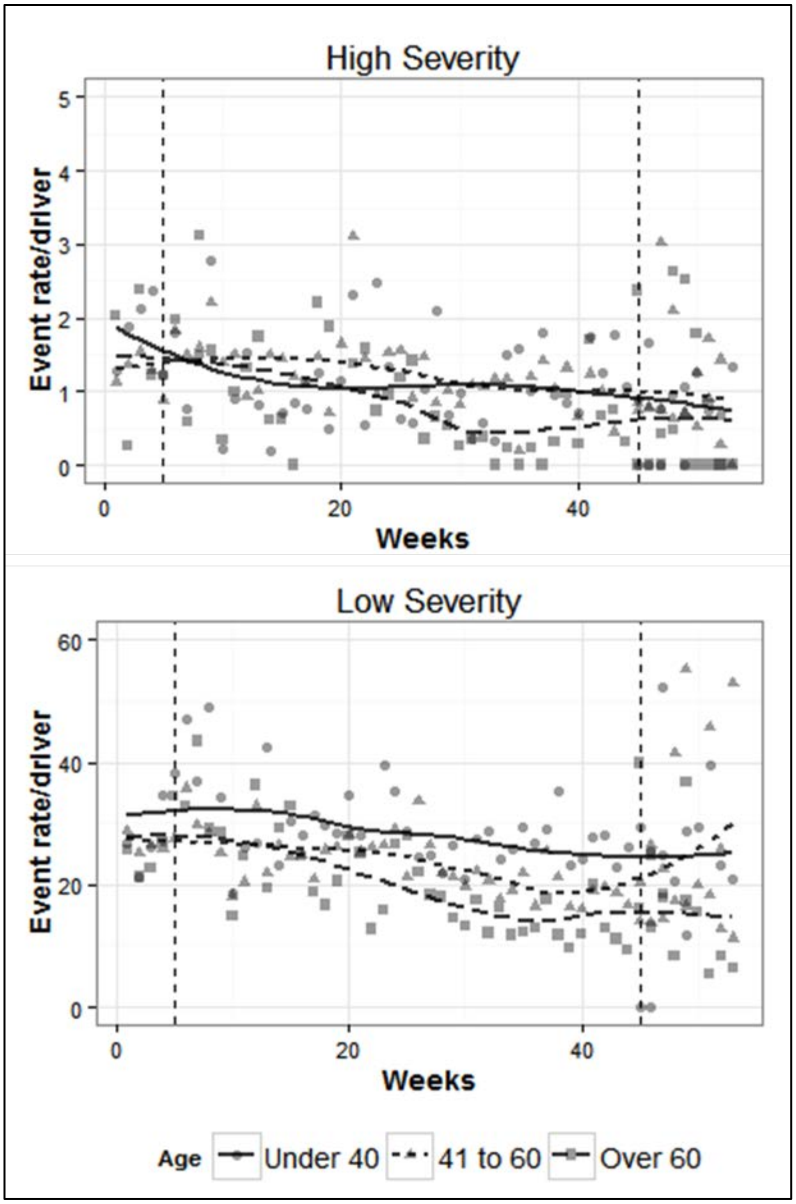


Figure 17. Graph. Mean event rate by age group.

3.2.2 Driver-level Approach: Repeated Measures Analysis of Variance

A separate repeated measures ANOVA was conducted for each fleet. The high-severity and low-severity events were also examined separately. As previously mentioned, a binary logit model was first applied to see whether drivers were more likely to engage in dangerous behaviors (critical event rate ≠ 0) during certain study phases. For drivers who were captured with any dangerous behaviors (critical event rate ≠ 0), a repeated measures ANOVA was further applied to detect any differences in event rate among phases and groups. Significant differences were further examined using pairwise comparisons with the Holm adjustment, which accounts for the overall experiment-wise error term. Significance was assessed at $\alpha = 0.05$.

3.2.2.1 Fleet A (Truck)

No covariates (i.e., group, phase, and interaction terms between them) in the two logit models were significant at the 0.1 level, suggesting that for high- and low-severity events, control and feedback group drivers in Fleet A were equally likely to engage in dangerous behaviors in all three phases.

For those drivers with at least one critical event, the high-severity event rate was significantly different between phases: $F(2, 85) = 54.48$, $p < 0.01$. More specifically, the baseline event rate in Fleet A (mean = 2.66 events per driver per 100 HOS) was significantly higher than the intervention (mean = 0.68) and withdrawal (mean = 0.90) event rates, as seen in Figure 18. However, the event rate in the withdrawal phase was significantly higher than that in intervention phase. No other outcomes were observed as significant.

For the low-severity event rates, there was also a significant difference between phases: $F(2, 145) = 22.86$, $p < 0.01$. For low-severity events, Fleet A had significantly lower event rates in the withdrawal phase (mean = 18.47 events per driver per 100 HOS) than in the intervention phase (mean = 21.31), which was significantly lower than the baseline phase (mean = 30.05). Given that no differences existed between the control and feedback groups, this trend was observed for all drivers who participated in the study. No other outcomes were observed as significant.

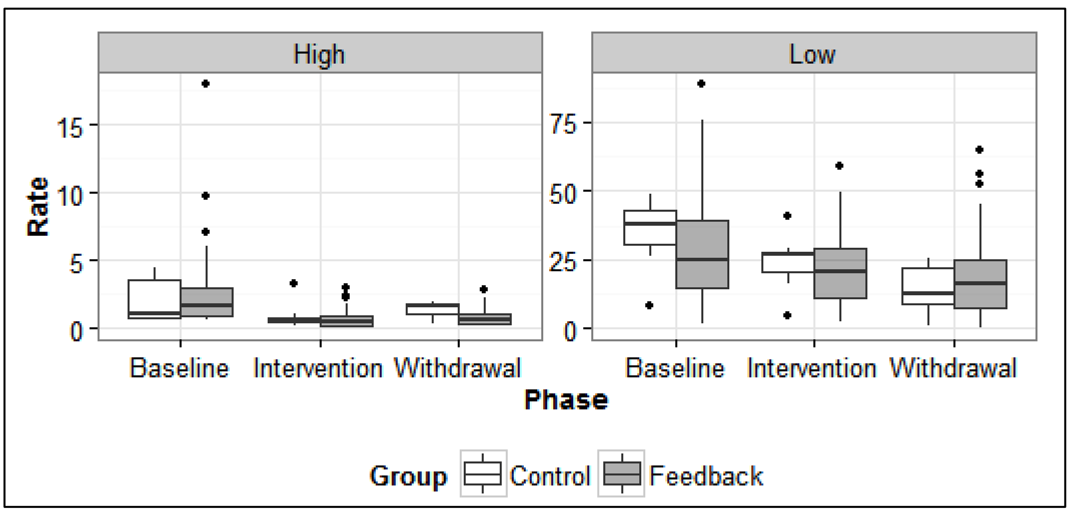


Figure 18. Graph. Mean event rates for high- and low-severity events (when critical event rate ≠ 0) for Fleet A.

3.2.2.2 Fleet H (Truck)

For high- and low-severity events, judging by the results of the binary logit models, with no estimated coefficients appearing to be significant at the 0.1 level, drivers in both the feedback and control groups in Fleet H were equally likely to engage in dangerous behaviors.

When the high-severity events were examined for Fleet H, a marginally significant difference was observed between groups: $F(1, 68) = 3.49$, $p = 0.06$. The control group had a lower event rate (mean = 1.11 per driver per 100 HOS) than the feedback group (mean = 3.51). However, as shown in Figure 19, event rates were observed with no significant differences in the baseline phase (mean = 5.11), intervention phase (mean = 2.99), and withdrawal phase (mean = 3.45) [$F(2, 62) = 1.08$, $p = 0.34$]. It should be noted that control group drivers had no system-captured critical events during the baseline phase. This probably resulted from the driver identification issues from weeks 2–5 and does not necessarily mean that the control group did better than the feedback group in the baseline phase.

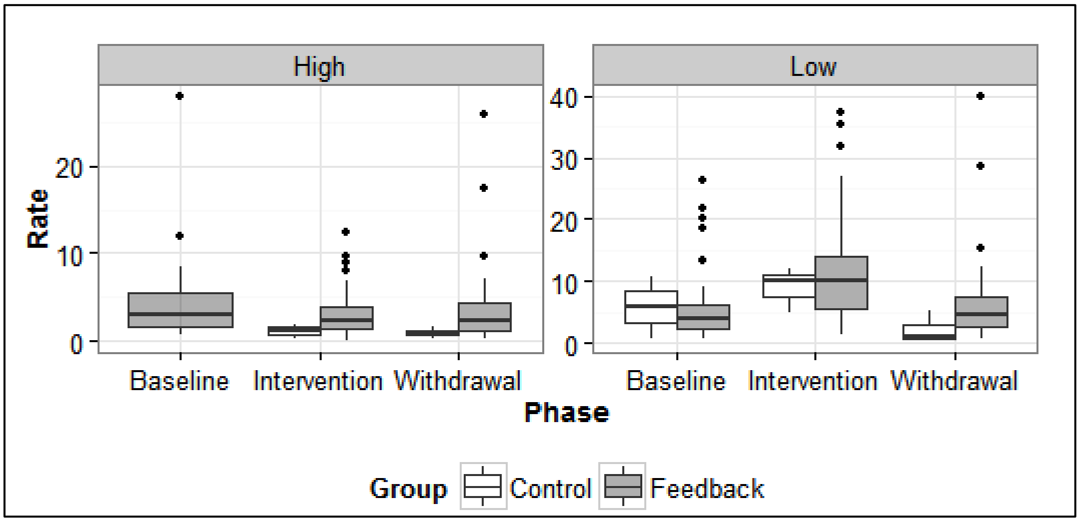


Figure 19. Graph. Mean event rates for high- and low-severity events for Fleet H (when critical event rate ≠ 0).

For low-severity events, there was a marginally significant main effect due to group: $F(1, 72) = 3.21$, $p = 0.08$. There was also a significant main effect of phase: $F(2, 94) = 30.32$, $p < 0.01$. Control group drivers in Fleet H (mean = 5.67) had a lower event rate than feedback group drivers (mean = 8.75), as seen in Figure 19. In Fleet H, the low-severity event rate was significantly lower in the baseline phase (mean = 7.21) than in the intervention phase (mean = 11.32), which was also significantly higher than in the withdrawal phase (mean = 6.07).

3.2.2.3 Fleet D (Motorcoach)

Two binary logit models were applied to high- and low-severity events. Similar to previously discussed findings, estimated coefficients of phase were not significant at the $\alpha = 0.05$ level, suggesting that drivers in Fleet D were equally likely to engage in dangerous behaviors in the baseline and intervention phases.

For high-severity events, significant differences were observed between these two phases for Fleet D: $F(1, 28) = 14.29$, $p < 0.01$. The pairwise t-test suggests that Fleet D had a significantly lower event rate in the intervention phase than in the baseline phase (mean = 1.84 and 3.04 events per driver per 100 HOS, respectively— see Figure 20, left panel). For low-severity events, the event rate was still significantly different between the two phases: $F(1, 41) = 20.14$, $p < 0.01$. Event rates in the intervention phase (mean = 49.45) were significantly higher than in the baseline phase (mean = 19.90).

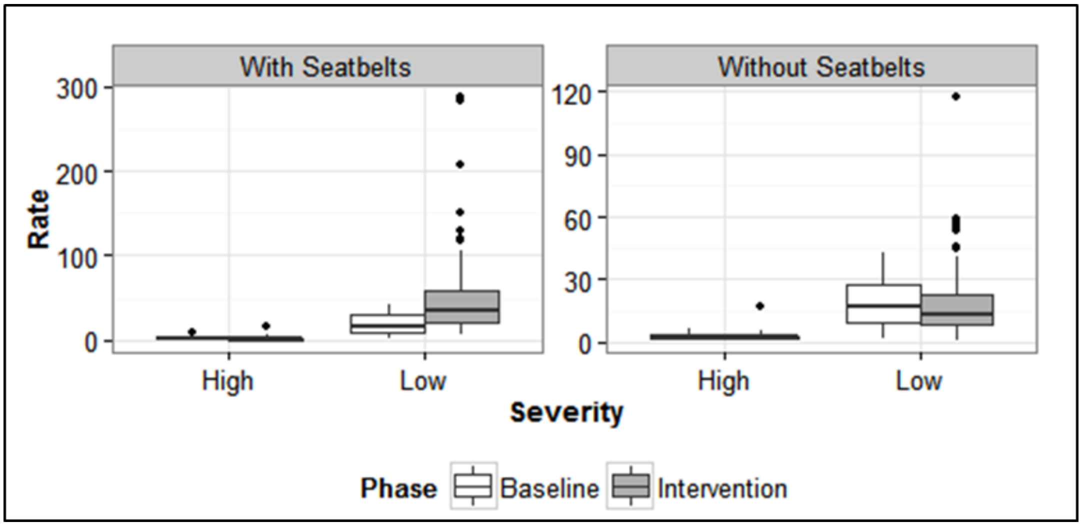


Figure 20. Graph. Mean event rates for high- and low-severity events (when critical event rate ≠ 0) for Fleet D for all events (left panel) and with seatbelts events removed (right panel).

Fleet D encountered technical issues with the detection of fastened seatbelts from the inception of the study. Judging by the number of events associated with seatbelts over time, this issue seemed more severe toward the end of the study, as shown earlier in Figure 14. Taking this into account, the research team removed all events associated with seatbelts and conducted the same analysis to see whether OBMS feedback (phase) might have any effects on the likelihood of engaging in dangerous behaviors and whether it would affect the event rate.

When unfastened-seatbelt events were removed, the logit model for high-severity events still had no significant estimates at the 0.1 level. Estimated coefficients of the intervention phase for low-severity events showed a trend toward significant ($p = 0.07$). The estimate is −1.916, indicating that drivers in the intervention phase were 0.15 times less likely to engage in dangerous behaviors than in the baseline phase.

For high-severity events, Fleet D had significantly lower event rates in the intervention phase than in the baseline phase (mean = 1.73 and 2.84, respectively; $F(1, 26) = 20.93$, $p < 0.01$—see Figure 20, right panel). For low-severity events, no significant differences were observed between phases: $F(1, 41) = 1.34$, $p = 0.25$. Fleet D had similar event rates in the baseline (mean = 18.34) and intervention (mean = 19.38) phases.

3.2.2.4 Fleet E (Motorcoach)

For Fleet E, the estimated coefficient of the intervention phase in the binary logit model for high-severity events was significant ($p < 0.01$). The estimate was 1.78, which indicates that drivers were 5.95 times more likely to engage in high-severity dangerous behaviors than in the baseline phase. The binary logit model for low-severity events had no significant coefficients at the 0.1 level, suggesting that drivers were equally likely to engage in low-severity dangerous behaviors in the two phases.

For the high-severity event rates, there was a significant main effect of phase: $F(1, 11) = 6.42$, $p = 0.03$. More specifically, Fleet E had lower event rates in the intervention phase (mean = 1.76) than in the baseline phase (mean = 2.79) (see Figure 21, left panel).

For low-severity events, the main effect of phase was still significant: $F(1, 23) = 78.27$, $p < 0.01$. Low-severity event rates in Fleet E were significantly lower in the intervention phase (mean = 28.99) than in the baseline phase (mean = 49.05) (see Figure 21, right panel).

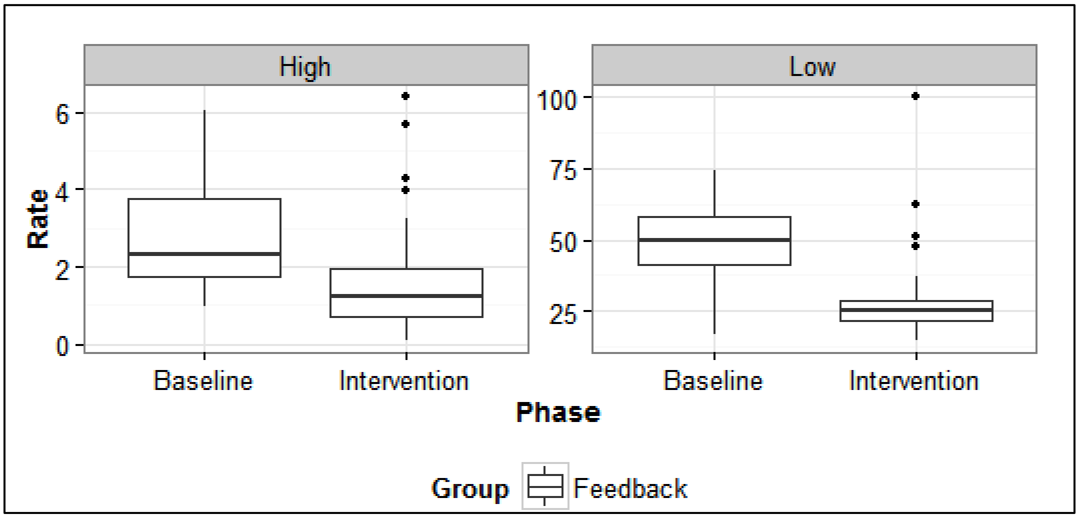


Figure 21. Graph. Mean event rates for high- and low-severity events (when critical event rate ≠ 0) for Fleet E.

3.2.3 Fleet-level Approach: Event Rate Reduction

All events and corresponding exposure data associated with all drivers participating in the study were aggregated for the fleet-level analyses. More specifically, the event rate reduction included all study participants (whether or not they were classified as “unknown”) except mechanics, drivers who did not volunteer for the study, and drivers in the control group.

3.2.3.1 Fleet A (Trucking)

In Fleet A, data were collected for 88 drivers in the baseline, intervention, and withdrawal phases. These drivers traveled a total of 5,024 miles in the baseline phase, 43,628 miles in the intervention phase, and 12,056 miles in the withdrawal phase. For these drivers, 156 high-severity events were collected in the baseline phase, 484 were collected in the intervention phase, and 103 were collected in the withdrawal phase.[ii] The high-severity event rate per 100 HOS changed from 3.1 in the baseline phase to 1.1 in the intervention phase and 0.9 in the withdrawal phase. The hypothesis test suggests that the reduced high-severity event rates in the intervention phase (64.3 percent) and in the withdrawal phase (72.5 percent) are both significant at the 0.05 significance level ($p < 0.001$ and $p < 0.001$).

[ii] The baseline phase lasted approximately 1 month, while the intervention phase lasted 9 months, and the withdrawal phase lasted 2 months. As a result, the number of events occurring in the intervention phase may appear higher (due to the extended time period), but the calculated event rate is actually lower.

A total of 2,737 low-severity events were collected in the baseline phase, 18,985 in the intervention phase, and 3,716 in the withdrawal phase. The low-severity event rate per 100 HOS decreased from 54.5 in the baseline phase to 43.5 in the intervention phase and 30.8 in the withdrawal phase. Based on a binomial distribution, these reductions are both significant ($p < 0.001$ and $p < 0.001$).

3.2.3.2 Fleet H (Trucking)

In Fleet H, data were collected for 74 drivers across all three phases. These drivers traveled 6,519 miles in the baseline phase, 56,916 miles in the intervention phase, and 12,203 miles in the withdrawal phase. For high-severity events, these drivers were involved in 334 events in the baseline phase, 2,476 in the intervention phase, and 306 in the withdrawal phase. The high-severity event rate per 100 HOS was 5.1 in the baseline phase, 4.4 in the intervention phase, and 2.5 in the withdrawal phase. Both the 15.1 percent reduction in the high-severity event rate in the intervention phase ($p = 0.003$) and the 51.1 percent reduction in the high-severity event in the withdrawal phase ($p < 0.001$) are significant when compared to baseline.

A total of 1,404 low-severity events were collected in the baseline phase, 7,727 in the intervention phase, and 803 in the withdrawal phase. The event rate changed from 21.5 in the baseline phase to 13.6 in the intervention phase and 6.6 in the withdrawal phase. Both event rate reductions (37 percent in the intervention phase and 69.4 percent in the withdrawal phase) are significant ($p < 0.001$) when compared to baseline.

3.2.3.3 Fleet D (Motorcoach)

In Fleet D, data were collected from 102 drivers in the baseline and intervention phases (Fleet D did not complete the withdrawal phase). These drivers traveled 8,552 miles in the baseline phase and 69,733 miles in the intervention phase. For these drivers, 126 high-severity events were collected in the baseline phase and 726 were collected in the intervention phase. The high-severity event rate for this fleet dropped from 1.5 in the baseline phase to 1.0 in the intervention phase. A hypothesis test (using a binomial distribution) showed that the 29.3 percent reduction in event rate is significant ($p < 0.001$). The percent reduction drops slightly to 28.7 when the unfastened-seatbelt events are removed from the analysis, but the outcome is still significant (p < 0.001).

A total of 1,519 low-severity events were collected in the baseline phase, and 26,881 events were collected in the intervention phase. The event rate in the baseline phase was 17.8, while the event rate in the intervention phase was 38.5. The event rate increased 117 percent in the intervention phase, which represents a significant increase ($p < 0.001$). It is important to note that this fleet experienced technical issues in detecting unfastened seatbelts, which may have affected the low-severity event rates.

3.2.3.4 Fleet E (Motorcoach)

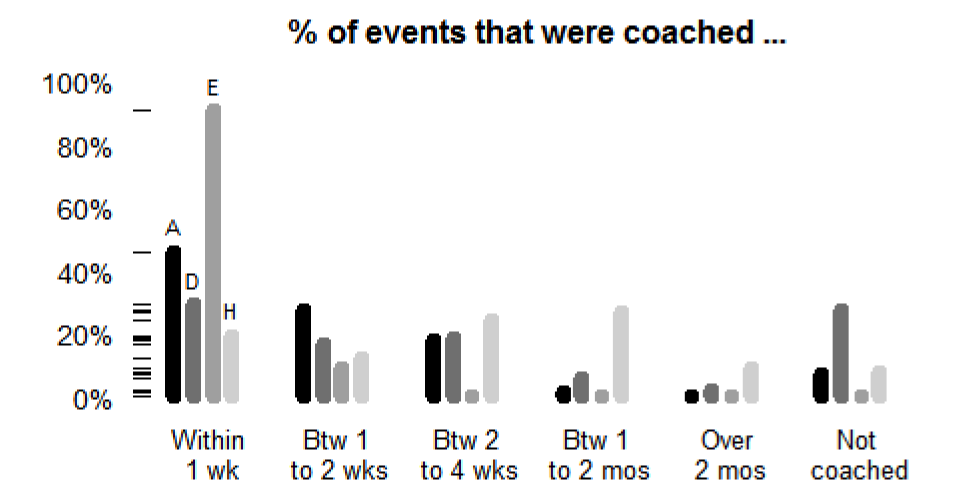
Fleet E included a baseline, an intervention, and a withdrawal phase. Nevertheless, due to some driver identification issues, all except four events that were recorded in the withdrawal phase (weeks 45–52) were associated with drivers not participating in the study. Moreover, all exposure data collected from weeks 38–42 and weeks 45–52 were associated with drivers not participating in the study. It was not clear how great an impact these non-participating drivers would have on the analysis; hence, no results are provided for Fleet E for weeks 38–42 and weeks 45–52 (the withdrawal phase).

In this fleet, data were collected for 40 drivers who traveled 2,494 miles in the baseline phase and 20,108 miles in the intervention phase. For these drivers, 50 high-severity events were collected in the baseline phase, and 303 were collected in the intervention phase. The event rate decreased from 2.0 in the baseline phase to 1.5 in the intervention phase. This 24.8 percent reduction is significant ($p = 0.028$) at the 0.05 significance level.

A total of 1,457 low-severity events were recorded in the baseline phase, and 5,450 were recorded in the intervention phase. The event rate in the baseline phase was 58.4, which decreased to 27.1 in the intervention phase. This amounts to a 53.6 percent reduction from the baseline to the intervention phase. The hypothesis test, which assumed a binomial distribution of the recorded events, suggests that this reduction is significant ($p < 0.001$).

3.2.4 Coaching

Along with the instant feedback provided by the OBMS in-vehicle, drivers also received coaching from safety managers. Fleet managers were able to customize their coaching policies; therefore, coaching policies may have differed slightly from fleet to fleet. Generally, safety managers were concerned with higher severity events. In this study, fleet managers from all four fleets coached high-severity events (severity levels 3 and 4). For Fleet A, certain types of observations (i.e., excessive speeding [> 10 mi/h over limit], unsafe following, mobile phone use, etc.) were coached, as well. For Fleets D and E, severity level 2 events were also coached. Drivers received one-on-one coaching with their safety managers as time permitted. Safety managers always used video clips recorded by the OBMS as a tool when coaching.Figure 22 shows coaching frequency, by fleet. As shown in Figure 22, 90.6 percent of the events that should have been coached were coached within 1 week in Fleet E. This percentage drops to 46 percent for Fleet A, 29 percent for Fleet D, and 19 percent for Fleet H. Upon further inspection of Figure 14 and Figure 15, the low-severity event rates for Fleet E decreased continually over time. This is observed for the fatigue, unfastened seatbelt, and speeding event rates, as well. The notable and continual decrease in event rate for this fleet may have been a direct benefit of their efficient coaching. Timely coaching appears to be very effective in reducing SCE rates, especially low-severity events.



	Within 1 wk	Btw 1 to 2 wks	Btw 2 to 4 wks	Btw 1 to 2 mos	Over 2 mos	Not coached
Fleet A	46.1%	27.2%	18.1%	1.6%		6.9%
Fleet D	29.4%	16.4%	18.7%	6.2%	1.8%	27.5%
Fleet E	90.6%	9.1%			0.2%	0.2%
Fleet H	19.4%	12.3%	24.3%	26.9%	9.2%	7.9%

Figure 22. Graph. Coaching in four fleets.

In Figure 23, solid grey lines show the number of events in need of coaching by week, and dotted black lines show the number of events that were coached in each week during the intervention phase. For Fleet E, the shape of the “events coached” line is quite similar to the “events needing coaching” line, with a lag of approximately 1 week. This indicates that events were coached mostly within 1 week for Fleet E, which coincides with the conclusion made from the previous figure. For Fleets A and D, these two lines have a similar shape, suggesting that events in these two fleets were efficiently coached, but not as efficiently as within Fleet E. Fleet H did not have much coaching until week 15. This, along with the delay in implementing instant feedback in this fleet, may explain why the event rate increased until around week 15. Judging by this figure and the event rate of the four fleets over time (shown in Figure 13), it seems that sporadic coaching (in Fleet H and in Fleet D after week 35), even after taking into account that a higher numbers of events were coached at one time, is less effective than timely coaching (i.e., coaching within 1 week).

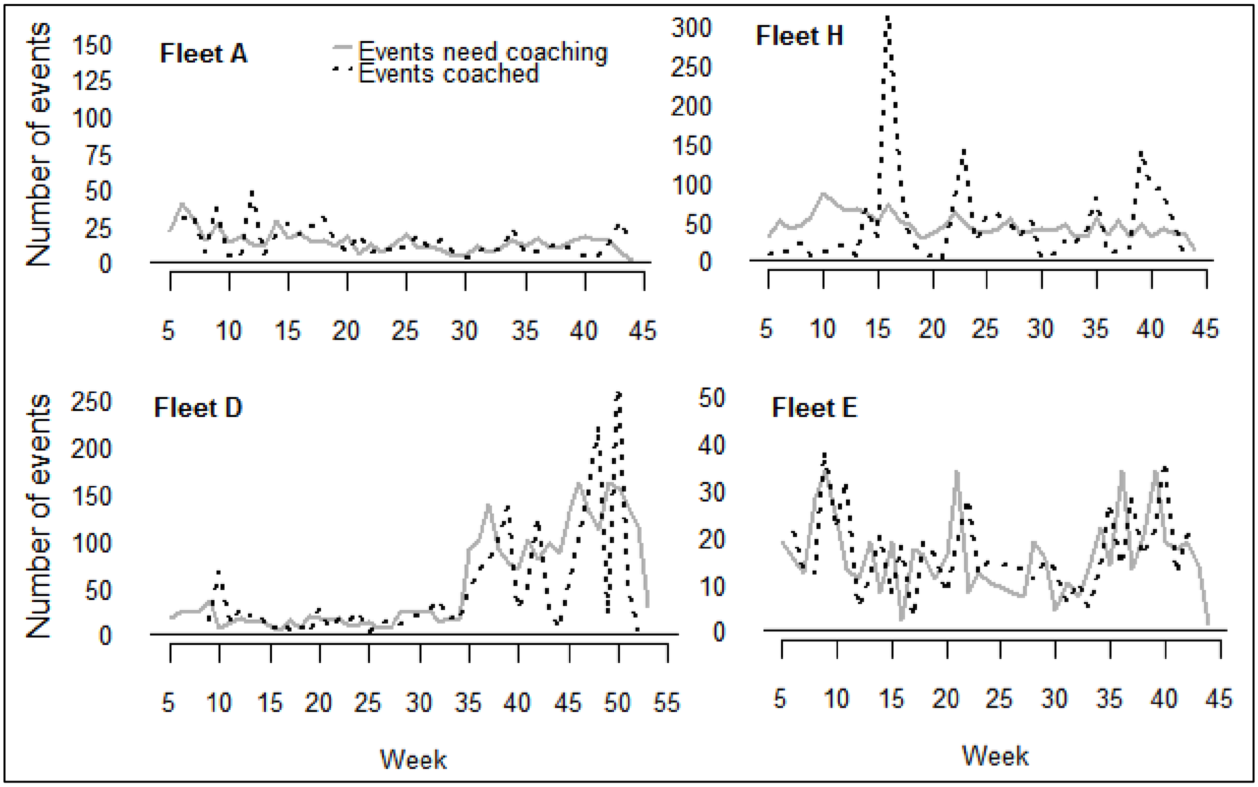


Figure 23. Graph. Number of events needing coaching and number of events coached, by week and fleet.

Based on the observed relationship between coaching and the change in driver event rate, the researcher would recommend that coaching be completed on a timelier basis to ensure the feedback is useful. Because timing options are highly dependent on the trucking operations, the researcher opted not to provide a specific timeframe for coaching. For example, some fleets can coach within a week, while others do not see their drivers for a few weeks or months at a time.

3.3 ATTITUDES TOWARD ONBOARD MONITORING SYSTEMS

The post-study questionnaire (see Appendices J and K) used a series of questions that were compared to the questions asked in the pre-study, baseline, feedback, and withdrawal questionnaires (see Appendices A–C). Summary statistics were computed and displayed for the questionnaires separately. Summary statistics for the safety managers' questionnaire are included in the third part of this section.

3.3.1 Pre-study, Baseline, Feedback, and Withdrawal Questionnaires

These questionnaires contained a series of questions regarding the drivers' and safety supervisors' opinions about the effectiveness of the OBMS. Answers to each question were recoded as numeric values using the following rule: strongly disagree = 1, disagree = 2, slightly disagree = 3, neutral = 4, slightly agree = 5, agree = 6, and strongly agree = 7. Mean values and standard deviations (SDs) of the answers to all questions were calculated separately for every month and for both groups. Although the control group had lower standard deviations within each month, their answers showed more fluctuation from month to month.

Detailed results for both feedback and control group drivers are provided below. However, this section focuses on the opinions of the feedback group drivers, as they received both instant warnings and coaching from safety supervisors.

The plots in Figure 24, Figure 25, Figure 26, Figure 27, and Figure 28 show the changes in drivers' opinions of the OBMS over time. The drivers had higher expectations for the OBMS in the pre-study and baseline questionnaires. The mean level of agreement dropped notably in the first month of the intervention phase. That is, drivers expressed more negative feelings toward the OBMS after feedback began. When asked in which situations the system was most useful (Q2 and Q6; Q = question), drivers gave consistent and stable answers for the six given situations. This could be because they were not very impressed by the system/feedback in any of the situations and therefore simply selected the same answers for all of the subcategories. Drivers registered more complaints about the system being annoying and distracting over time. For the four questions that asked for drivers' feelings about the system, instant feedback, cumulative feedback, and safety manager coaching (Q3 and Q7–Q9), drivers typically reported a neutral opinion at the pre-study and baseline phases, but at the beginning of the intervention phase, noted that they "slightly agreed" that the system and feedback were annoying and distracting. Drivers' attitudes were relatively similar throughout the intervention phase. The drivers expressed more negative opinions by the first questionnaire of the withdrawal phase. In general, drivers were mostly ambivalent about (i.e., neutral), if not leery of, the usefulness of systems.

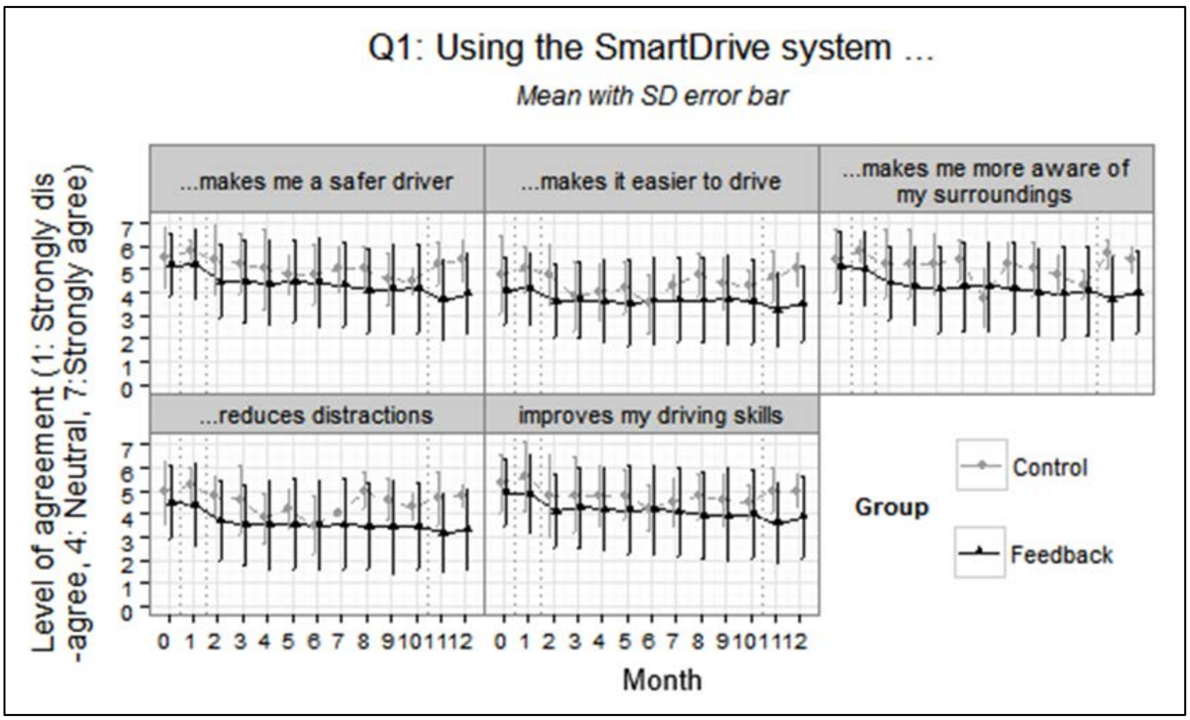


Figure 24. Chart. Drivers' responses to Q1.*

*Month 0 corresponds to the pre-study questionnaire, month 1 corresponds to the baseline questionnaire, months 2–10 correspond to the intervention questionnaire, and months 11–12 correspond to the withdrawal questionnaire.

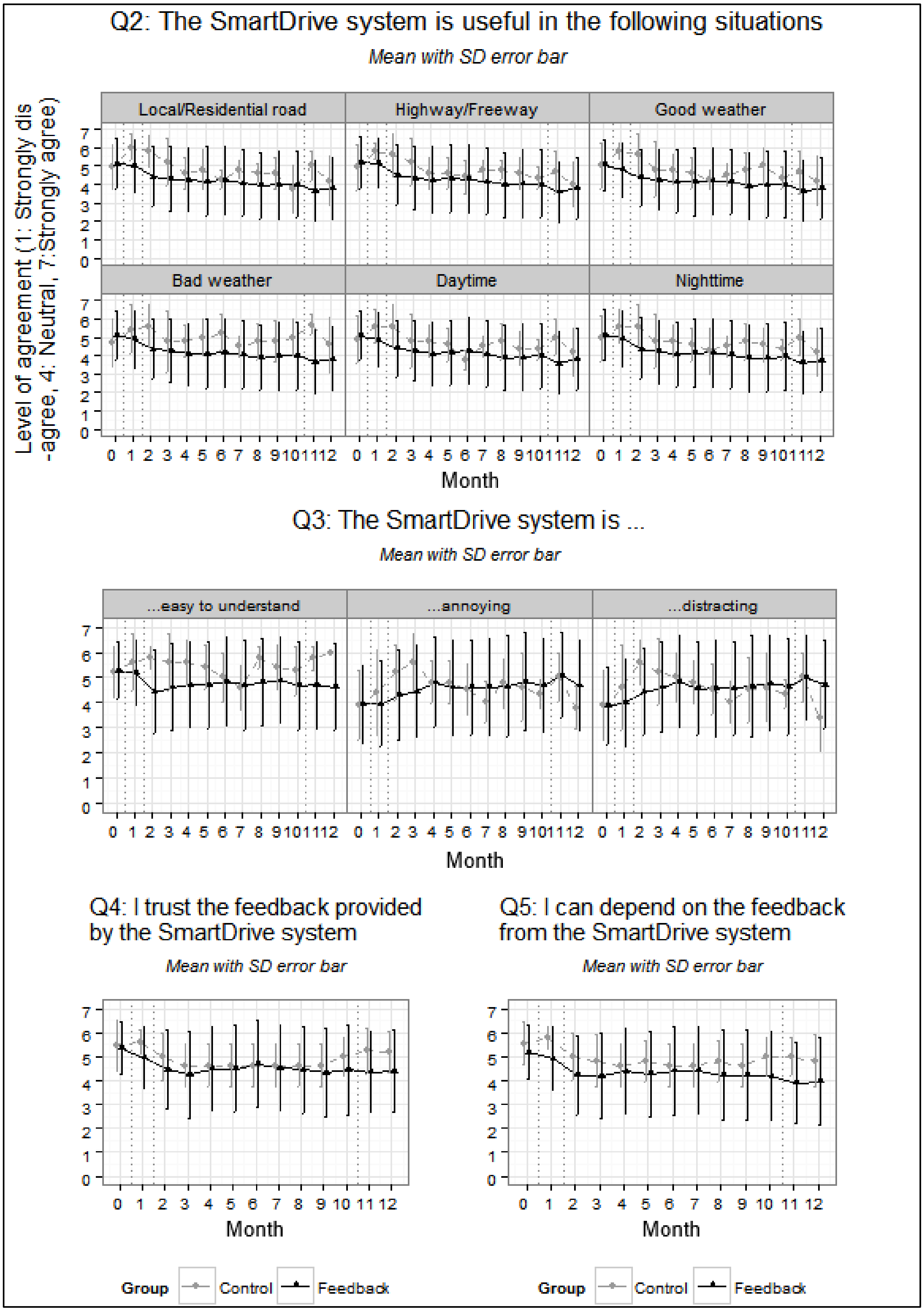


Figure 25. Chart. Drivers' responses to Q2, Q3, Q4, and Q5.

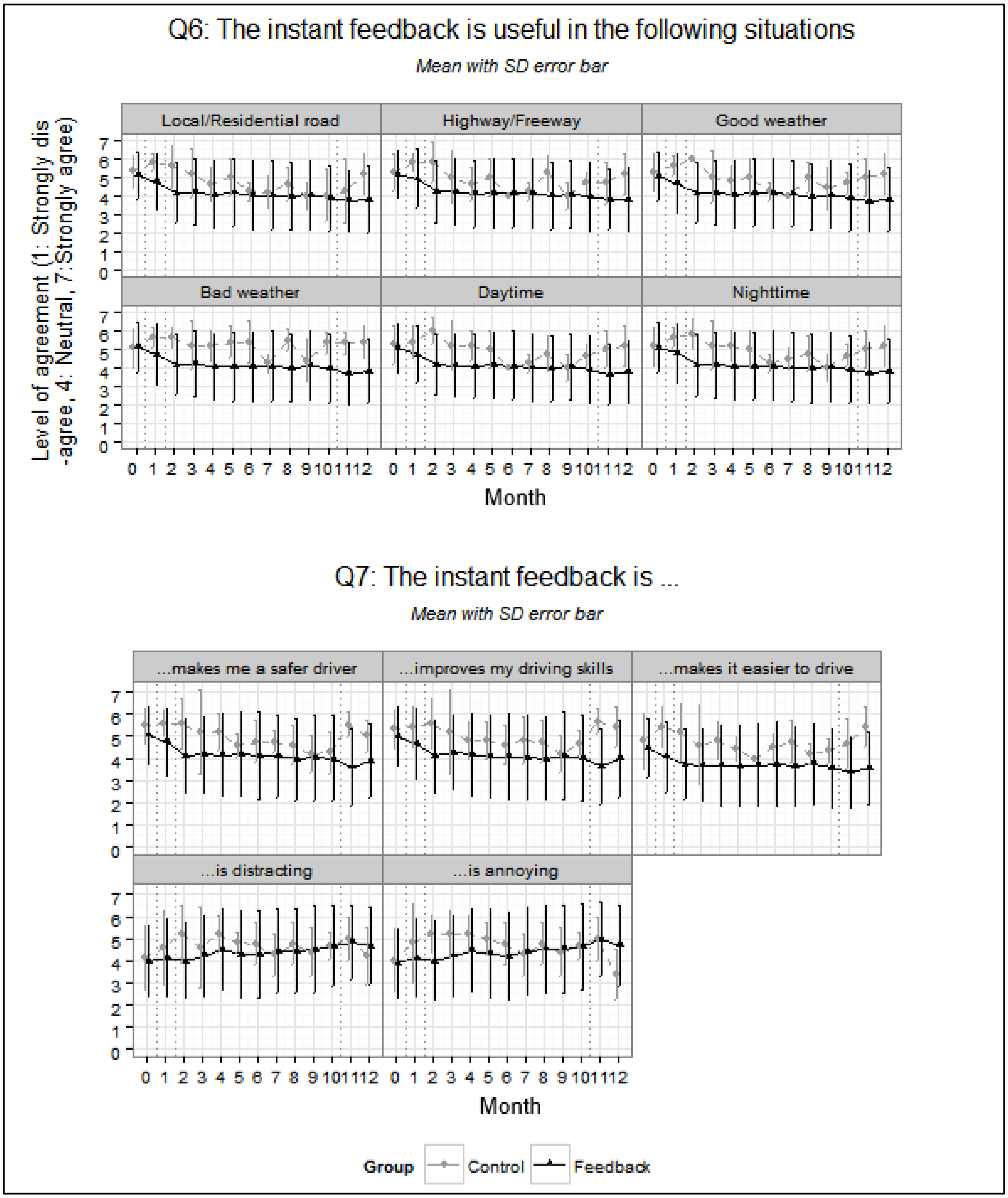


Figure 26. Chart. Drivers' responses to Q6 and Q7.

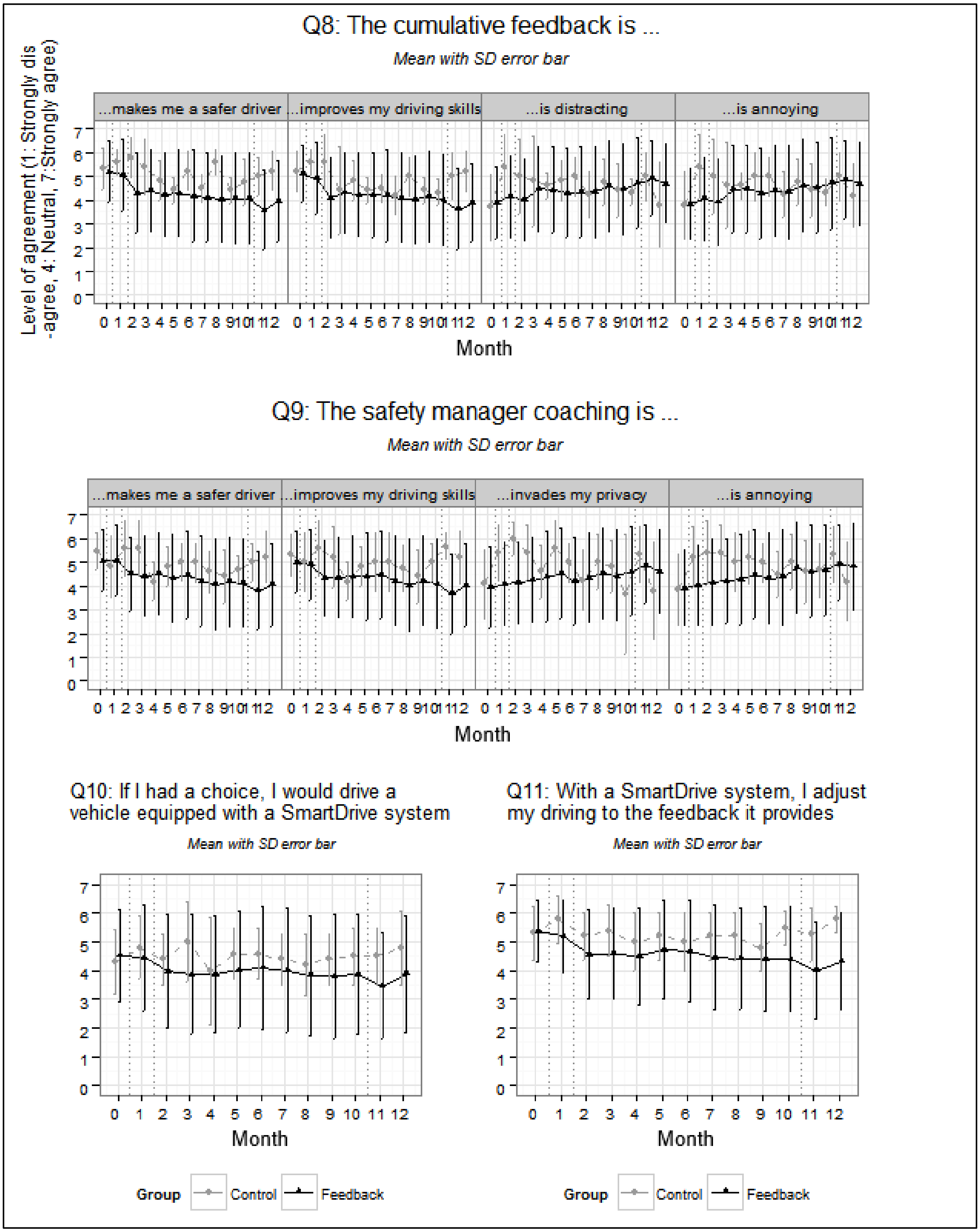


Figure 27. Chart. Drivers' responses to Q8, Q9, Q10, and Q11.

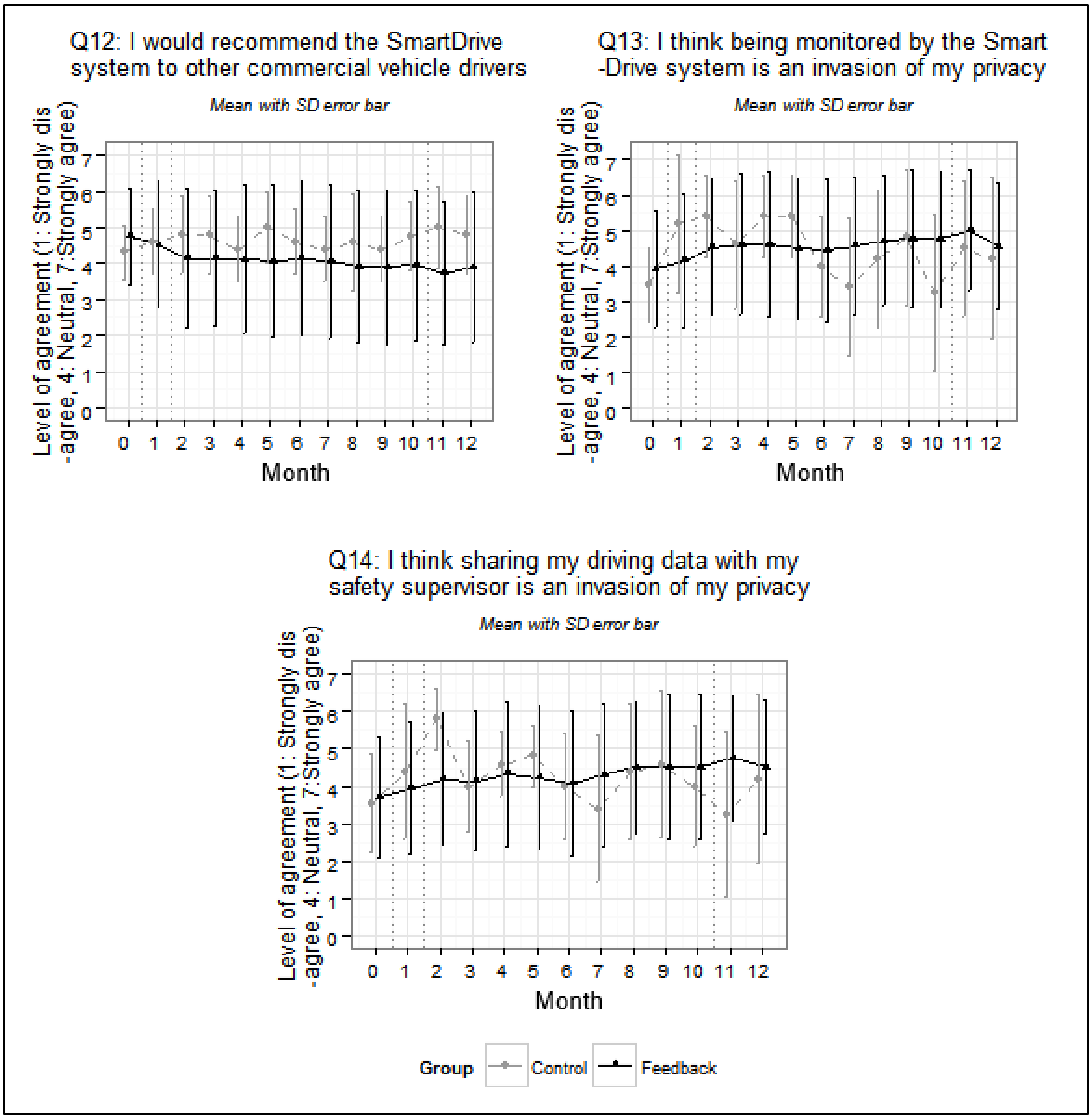


Figure 28. Chart. Drivers' responses to Q12, Q13, and Q14.

3.3.2 Post-study Questionnaire

The post-study questionnaire was administered at the same time as the last withdrawal questionnaire, but included a set of different questions regarding drivers' opinions (see Appendices J and K). Answers to the first four questions were recoded as: 1 = strongly disagree, 2 = disagree, 3 = slightly disagree, 4 = neutral, 5 = slightly agree, 6 = agree, and 7 = strongly agree. Answers to Q5–Q7 were also recoded numerically as: 1 = much less effective, 2 = moderately less effective, 3 = slightly less effective, 4 = equally effective, 5 = slightly more effective, 6 = moderately more effective, and 7 = much more effective. Mean values and standard deviations of answers to all questions were computed separately for feedback and control groups (as shown in Table 8). Control group drivers appeared to have more positive attitudes toward the benefits of the OBMS. In general, the opinions of the feedback group drivers were still fairly positive for the post-study questionnaire, as the mean was greater than 4.

Table 8. Means and standard deviations of answers for the post-study questionnaire for the control and feedback groups.

Group	Questions	Mean	SD
Control	Q1: I think using the OBMS has made drivers in my company more aware of unsafe driving behaviors	5.75	(0.50)
Control	Q2: I think using the OBMS has increased my safety supervisor's concern for driving safety.	4.25	(1.70)
Control	Q3: People who are inside the company and influence my behavior think that the OBMS makes me a safer driver	5.00	(0.82)
Control	Q4: People who are outside the company and influence my behavior think that the OBMS makes me a safer driver.	5.00	(1.15)
Feedback	Q1: I think using the OBMS has made drivers in my company more aware of unsafe driving behaviors	4.92	(1.54)
Feedback	Q2: I think using the OBMS has increased my safety supervisor's concern for driving safety.	4.78	(1.60)
Feedback	Q3: People who are inside the company and influence my behavior think that the OBMS makes me a safer driver	4.65	(1.52)
Feedback	Q4: People who are outside the company and influence my behavior think that the OBMS makes me a safer driver.	4.25	(1.47)
Feedback	Q5: Coaching from my supervisor was effective in improving my driving safety.	4.58	(1.68)
Feedback	Q6: Compared to warnings from the OBMS, coaching from my safety supervisor was….	4.20	(1.70)
Feedback	Q7: Compared to warnings from the OBMS, coaching from my safety supervisor on the following events was…	-	-
Feedback	1. Hard braking	4.04	(1.73)
Feedback	2. Hard accelerating	4.03	(1.70)
Feedback	3. Swerving	3.96	(1.67)
Feedback	4. Speeding	4.29	(1.73)

Note: The scale for Q1–Q5 was as follows: 1 = strongly disagree, 2 = disagree, 3 = slightly disagree, 4 = neutral, 5 = slightly agree, 6 = agree, and 7 = strongly agree. The scale for Q5–Q7 was as follows: 1 = much less effective, 2 = moderately less effective, 3 = slightly less effective, 4 = equally effective, 5 = slightly more effective, 6 = moderately more effective, and 7 = much more effective.

Figure 29 shows the distribution of responses to Q1–Q5 for drivers in the feedback group. Feedback group drivers typically agreed that the OBMS made them safer drivers and helped to improve safety awareness in their company.

Q6 and Q7 solicited information on the effectiveness of coaching compared to real-time feedback, as shown in Figure 30. Drivers' opinions tended to be neutral for these two questions.

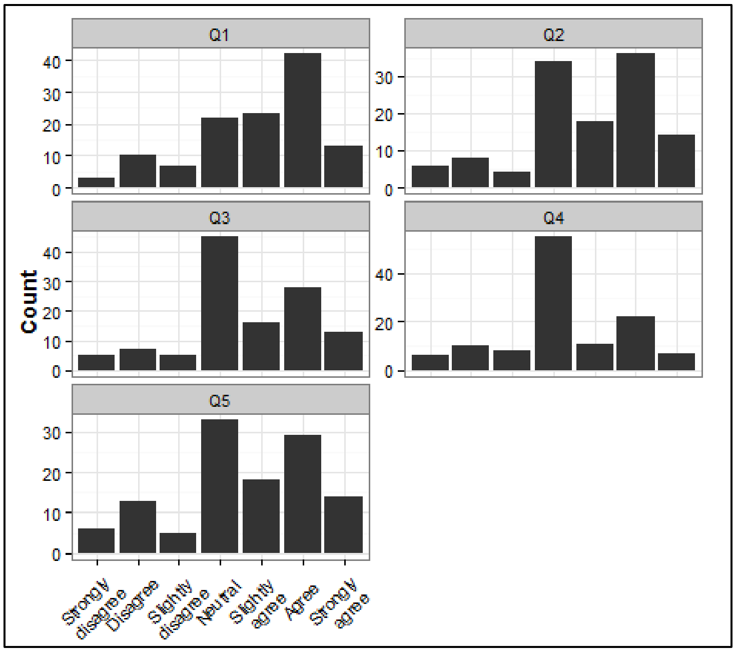


Figure 29. Chart. Response frequency for Q1–Q5 for the feedback group.

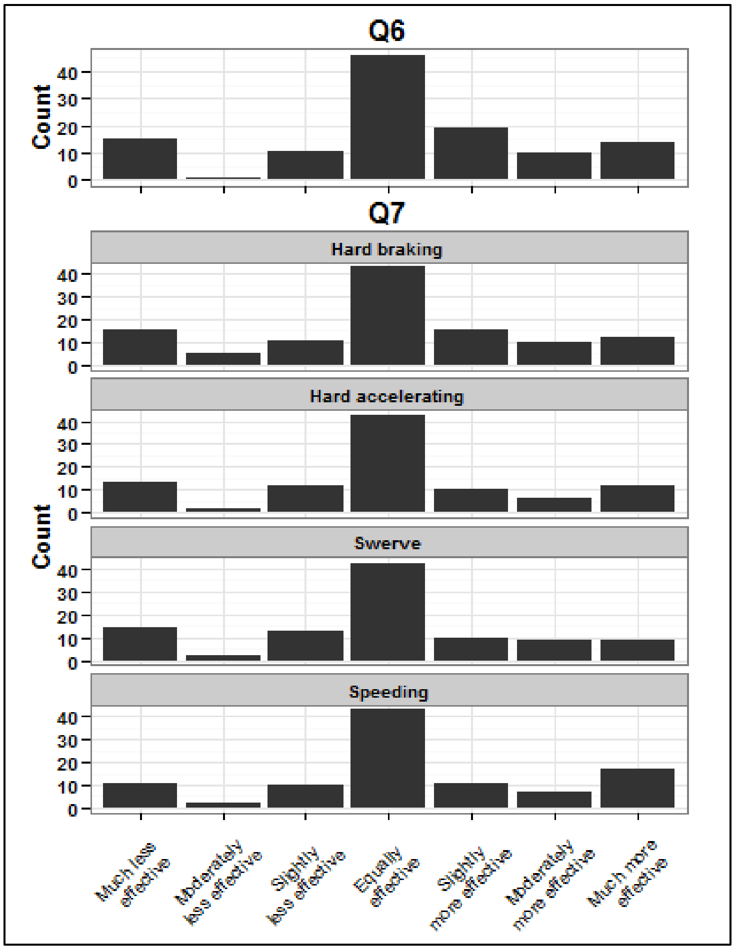


Figure 30. Chart. Response frequency for Q6 and Q7 for the feedback group.

The questionnaire also included several comments from participants. Drivers who were satisfied with the system and the coaching from safety supervisors thought the following:

- The OBMS makes drivers more aware of unsafe behaviors and they thereby adjust their driving to perform more safely.
- The OBMS makes drivers more conscious of their surroundings.
- The OBMS helps to improve their driving skills.
- Instant warnings keep drivers from speeding.
- The OBMS provides safety supervisors with a tool to coach and helps them to be more aware of how the drivers are driving.
- Safety supervisors helped to explain what the drivers were doing wrong and helped improve their driving behavior.

Drivers who were less satisfied with the system and coaching complained about the following:

- The OBMS is distracting: drivers tend to pay more attention to symbols instead of watching the road.
- Safety supervisors are not at the scene and videos are sometimes not long enough to show the situation.
- The driver-facing camera makes them feel like they are being watched and is an invasion of their privacy.
- The OBMS is too sensitive.
- The warning light is too bright in the nighttime.

Most drivers found the system easy to understand; however, some were confused by the warnings, as they could not relate the alert back to what they may have done wrong.

3.3.3 Pre- and Post-study Questionnaire for Safety Managers

Ten safety managers from Fleets A, E, and H responded to the questionnaires. On average, these safety managers had been with their companies for 11.9 years (range: 2.4–22.5) and had been safety supervisors at their current companies for 10.8 years (range: 2.4–22.5). Managers supervised/coached an average of 45 drivers in the month (range: 0–83) before the post-study questionnaire was administered. Although the safety managers were not driving in this study and had no direct contact with the OBMS, they were able to access all records for participants' driving performance and were supposed to use these records for coaching purposes. This gave the safety managers a basis for evaluating the OBMS.

Eight of the 10 safety managers participated in both the pre-study and the post-study questionnaires. The response scale was as follows: 1 = strongly disagree, 2 = disagree, 3 = slightly disagree, 4 = neutral, 5 = slightly agree, 6 = agree, and 7 = strongly agree. Mean values and standard deviations of safety managers' answers to all questions are provided in Table 9.

Table 9. Means and standard deviations of safety managers' answers to the pre- and post-study questionnaires.

Question	Pre-study: Mean (SD)	Post-Study: Mean (SD)
Q1: Using the OBMS…makes drivers a safer driver	6.71 (0.52)	6.62 (0.52)
Q1: Using the OBMS…makes it easier to drive	4.71 (1.64)	5.12 (1.64)
Q1: Using the OBMS…makes drivers more aware of their surroundings	6.57 (0.53)	6.50 (0.53)
Q1: Using the OBMS…reduces distractions	5.43 (1.19)	5.62 (1.19)
Q1: Using the OBMS…improves drivers' driving skills	6.43 (0.71)	6.25 (0.71)
Q2: OBMS is useful in the following situation: local/residential road	6.43 (0.74)	6.38 (0.74)
Q2: OBMS is useful in the following situation: highway/freeway	6.57 (1.04)	6.25 (1.04)
Q2: OBMS is useful in the following situation: good weather	6.43 (0.99)	5.88 (0.99)
Q2: OBMS is useful in the following situation: bad weather	6.86 (0.71)	6.25 (0.71)
Q2: OBMS is useful in the following situation: daytime	6.43 (0.93)	6.00 (0.93)
Q2: OBMS is useful in the following situation: nighttime	6.71 (0.64)	6.12 (0.64)
Q3: OBMS is...easy to understand	6.57 (0.52)	6.38 (0.52)
Q3: OBMS is...annoying	3.29 (1.69)	3.62 (1.69)
Q3: OBMS is...distracting	3.00 (1.69)	3.00 (1.69)
Q4: I trust the feedback provided by the OBMS	6.80 (0.75)	6.17 (0.75)
Q5: The instant feedback was useful to drivers in the following situations:	-	-
• Local/residential road	6.60 (0.52)	6.33 (0.52)
• Highway/freeway	6.80 (0.55)	6.50 (0.55)
• Good weather	6.60 (0.41)	6.17 (0.41)
• Bad weather	7.00 (0.41)	6.17 (0.41)
• Daytime	6.60 (0.41)	6.17 (0.41)
• Nighttime	7.00 (0.41)	6.17 (0.41)
Q6: The instant feedback...makes drivers safer	6.60 (1.21)	6.33 (1.21)
Q6: The instant feedback...improves drivers' driving skills	6.60 (1.17)	6.17 (1.17)
Q6: The instant feedback...makes it easier to drive	5.25 (1.33)	5.17 (1.33)
Q6: The instant feedback...is distracting	2.40 (1.51)	3.67 (1.51)
Q6: The instant feedback...is annoying	2.40 (1.47)	3.83 (1.47)
Q7: The cumulative feedback...makes drivers safer	6.40 (0.52)	6.33 (0.52)
Q7: The cumulative feedback...improves drivers driving skills	6.60 (0.52)	6.33 (0.52)
Q7: The cumulative feedback...is distracting	2.60 (1.51)	3.33 (1.51)
Q7: The cumulative feedback...is annoying	2.80 (1.33)	3.17 (1.33)
Q8: The safety manager coaching...makes drivers safer	6.43 (0.76)	6.50 (0.76)
Q8: The safety manager coaching...improves drivers' driving skills	6.43 (0.74)	6.38 (0.74)
Q9: I feel it would be useful to install OBMS as standard equipment in commercial vehicles	6.57 (0.52)	6.38 (0.52)
Q10: I think the OBMS will improve the overall commercial vehicle driver's safety	6.29 (0.52)	6.38 (0.52)
Q11: I would recommend the OBMS to my friends or colleagues.	5.57 (0.52)	6.38 (0.52)
Q12: I would recommend the company to install OBMS for all commercial vehicles in the future as standard equipment	5.86 (0.52)	6.38 (0.52)

In general, safety managers had relatively similar attitudes towards the OBMS before and after the study. The biggest variation in opinion came from Q7. Safety managers disagreed that the instant feedback was annoying before the study began, but after the study they tended to have more neutral opinions. Safety managers tended to agree that the OBMS, along with the instant feedback and cumulative feedback, benefited the drivers in that it made them safer, helped them to be more aware of their surroundings, and helped to improve their driving skills. They tended to disagree that the OBMS and feedback were annoying or distracting. Compared to the responses from the drivers, safety managers had a greater likelihood of having more positive attitudes toward the OBMS.

3.3.4 Cluster Analysis

A cluster analysis was used to group drivers based on several responses from the first (pre-study) questionnaire and the last (second withdrawal) questionnaire. A total of 137 drivers from Fleets A, D, E, and H participated in the questionnaire; 84 of these drivers were in the feedback group and provided responses to the questions of interest for the first and last questionnaires.

Differences in responses to seven of the questions were used to cluster drivers. The correlations among the questions are shown in Table 10. These questions were:

- Q1.1: I think using the OBMS makes me a safer driver.
- Q1.3: I think using the OBMS makes me more aware of my surroundings.
- Q3.1: I think the OBMS is easy to understand.
- Q3.3: I think the OBMS is distracting.
- Q10: If I had a choice, I would drive a commercial vehicle equipped with an OBMS.
- Q11: If I had an OBMS, I would adjust my driving to the feedback it provides.
- Q13: I think being monitored by the OBMS will be an invasion of my privacy.

Table 10. Correlation table of the cluster variables.

Question Number	Q1.1	Q1.3	Q3.1	Q3.3	Q10	Q11	Q13
Q1.1	1.00	0.67	0.50	-0.29	0.36	0.59	-0.17
Q1.3	0.67	1.00	0.46	-0.30	0.38	0.60	-0.28
Q3.1	0.50	0.46	1.00	-0.11	0.43	0.48	-0.19
Q3.3	-0.29	-0.30	-0.11	1.00	-0.35	-0.23	0.50
Q10	0.36	0.38	0.43	-0.35	1.00	0.48	-0.37
Q11	0.59	0.60	0.48	-0.23	0.48	1.00	-0.37
Q13	-0.17	-0.28	-0.19	0.50	-0.37	-0.37	1.00

The cluster analysis was examined using the within group sum of squares (WSS) to determine the number of meaningful clusters. The WSS appeared to level off around four clusters, and these four clusters explained 50.4 percent of the variability. The separation of clusters is shown in Figure 31.

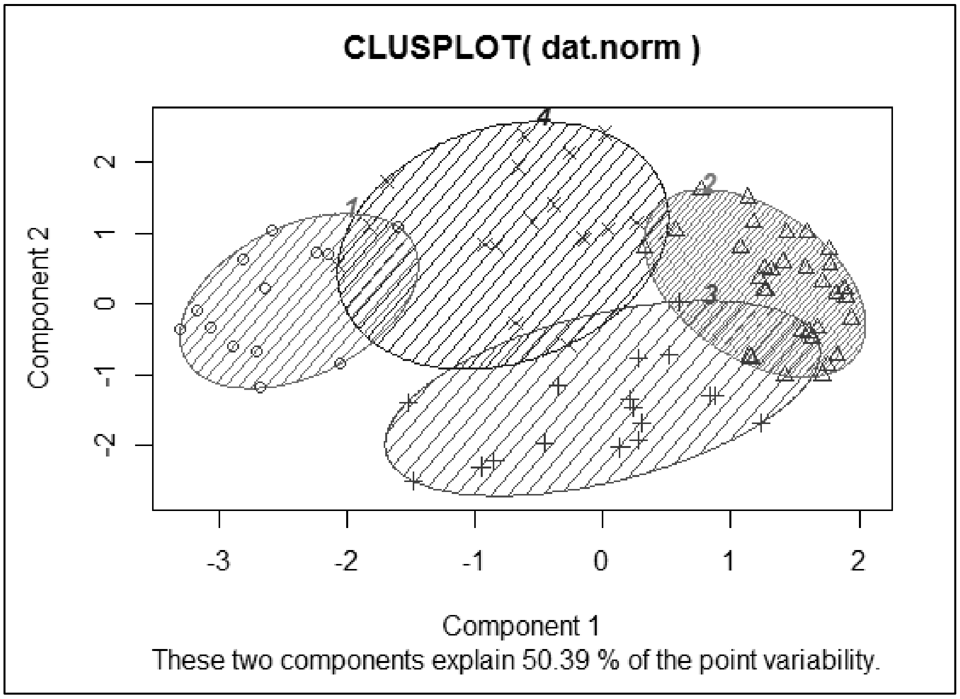


Figure 31. Diagram. Separation of responses for the four-cluster solution.

The mean difference in agreement between the last and first questionnaire by cluster groups is shown in Table 11. Each response was recorded on a scale from 1 (strongly disagree) to 7 (strongly agree).

Table 11. Mean difference between last and first questionnaire.

Question	Group 1 (n=13)	Group 2 (n=33)	Group 3 (n=17)	Group 4 (n=21)	Total
Q1.1: I think using the OBMS…makes me a safer driver	0.69	-2.55	0.53	-1.29	-1.11
Q1.3: I think using the OBMS…makes me more aware of my surroundings	0.62	-2.52	0.53	-0.81	-0.99
Q3.1: I think the OBMS is…easy to understand	1.08	-1.30	-0.71	-0.24	-0.55
Q3.3: I think the OBMS is…distracting	-1.38	1.91	-0.06	0.29	0.60
Q10: If I had a choice, I would drive a commercial vehicle equipped with an OBMS	0.92	-1.85	-1.06	0.67	-0.63
Q11: If I had a OBMS , I would adjust my driving to the feedback it provides	0.08	-2.79	-0.29	-0.29	-1.21
Q13: I think being monitored by the OBMS will be an invasion of my privacy	-1.08	1.97	1.24	-0.90	0.63

The following is a description of the results for each group’s reactions to the questionnaires.

- On the scale in the pre-study questionnaire, **Groups 1, 2, and 3** fell somewhere between “neutral” and “slightly agree” regarding the benefits of the OBMS.

- **Group 1** was the most satisfied with the OBMS. This group was more likely to agree with the benefits of the OBMS and less likely to report that the OBMS was distracting or invaded drivers' privacy.
- **Group 2** was the most unsatisfied with the OBMS. After using this system, this group was less likely to agree with the benefits of the OBMS and believed that it was distracting and invaded drivers' privacy.
- By the last questionnaire, drivers in **Group 3** indicated greater confidence in the OBMS's capabilities to make them aware of their surroundings and to help them become safer drivers. However, there was only a marginal difference ($\chi^2(6) = 11.90$, $p = 0.06$) between the first and last questionnaire regarding how distracting the system was.
- **Group 3** progressively "agreed" that the OBMS invaded drivers' privacy and progressively "disagreed" that it was easy to understand. That is, this group believed that the OBMS had more disadvantages than advantages, and therefore became less interested in driving commercial vehicles with the OBMS after use.
- Agreement that the OBMS made them safer drivers and helped them become more aware of their surroundings decreased for **Group 4**. This group was also less likely to believe that the system invaded drivers' privacy. Interestingly, even though drivers in Group 4 had less confidence in the benefits of the OBMS after using it, they were more willing to use a commercial vehicle equipped with an OBMS.

In summary:

- **Group 1: Satisfied with the OBMS.**
  - Compared to the other three groups, Group 1 had the highest expectations (in the pre-study questionnaire) for the system and did not think the system would be annoying, distracting, or invade drivers' privacy. These drivers indicated that they would like to drive a commercial vehicle equipped with an OBMS and would consider adjusting their driving based on the feedback.
  - After using the OBMS, drivers in Group 1 became even more satisfied with the system. They "slightly agreed" or "agreed" with the benefits of the OBMS and "disagreed" that the system was annoying, distracting, or invaded their privacy. These drivers were also more likely to agree that they would like to drive a commercial vehicle equipped with an OBMS in the future, and they would likely recommend it to other drivers.
- **Group 2: Unsatisfied with the OBMS.**
  - Compared to the other three groups, Group 2 was more likely to agree that the system (including feedback and coaching) would be annoying or distracting in the pre-study questionnaire. These drivers were less likely to trust the system and feedback and typically less likely to agree that they would like to drive a commercial vehicle equipped with an OBMS.
  - This group had the largest variation in responses between the first and last questionnaires. In general, these drivers became very unsatisfied with the system and

reported negative opinions about the system from every perspective after system use. They "disagreed" or "slightly disagreed" with the benefits of the OBMS. They noted that feedback and coaching were annoying, distracting, and an invasion of drivers' privacy. These drivers indicated that they would not like to use vehicles equipped with an OBMS in the future, and they would not recommend it to other drivers.

- **Group 3: Began with lower expectations.**
  - In the pre-study questionnaire, Group 3 reported the lowest opinions of the OBMS compared to the other three groups; however, these drivers did note that they would like to use a commercial vehicle equipped with an OBMS and would like to recommend it to other drivers.
  - These drivers' attitudes about the system did not change too much after using the system. In fact, this group had the least amount of change in response compared to the other three groups. The largest change was related to privacy concerns (Q13). Drivers in this group became more likely to agree that being monitored by the OBMS was an invasion of their privacy. This may be why these drivers lowered their level of agreement slightly with regard to driving a vehicle equipped with an OBMS or recommending that other drivers use an OBMS.
- **Group 4: Began with higher expectations.**
  - In the pre-study questionnaire, Group 4 had the greatest expectations for the OBMS when compared to the other three groups. These drivers also had the highest level of agreement that being monitored by the OBMS would be an invasion of their privacy.
  - After using the system, this group had slightly more negative opinions about the system but still had neutral opinions or "slightly agreed" with the benefits of the OBMS. In terms of the potential privacy issue of the OBMS, these drivers were actually less likely to agree that the system invaded their privacy after using it. This may be the reason why they became more likely to agree that they would like to drive a commercial vehicle equipped with an OBMS and would likely recommend it to other drivers.

3.4 CRASH REDUCTION

The analysis in Section 3.2, which evaluates the safety effects of the OBMS using safety event data, employs an analysis method used in previous OBMS-related studies. In 2009, Hickman and Hanowski looked at OBMS data collected from 100 OBMS-equipped tractor-trailers that provided information to drivers through a feedback light.[21] In this study, safety managers could also use a coaching protocol provided by the program to coach drivers on their safety-related events. The analysis in this 2009 study considered how the mean rate of safety-related driving events changed from pre-intervention to intervention. To the knowledge of the research team, studies of OBMS efficacy have focused on using safety event data without considering the impact on actual crashes of concern to fleets. Taking a multi-pronged approach to assessing the effects of an OBMS on fleet safety, the current study analyzes crash and mileage data collected by the fleets themselves. This approach may best reflect the method a fleet might use to assess system effectiveness, as it relies on data that the fleet already collected. Fleet crash data is different from safety event data, in that it consists almost entirely of crashes and more severe events.

The crash and mileage data used in the following analysis was previously collected by the fleets for their own records. Three fleets in the study provided this fleet-collected crash and mileage data, for both the pre-intervention and intervention phases.[iii] The raw data included crash summaries for each crash. Researchers used the crash summaries to determine "claims only" status for each crash. Claims-only crashes are defined as "curb strikes, mechanical failures, non-vehicle-to-vehicle crashes in a parking lot, non-contact conflicts, backing into a dock, vehicle parked when hit, and vandalism." [(22)] All crashes classified as "claims only" were excluded from the analysis; the remaining crashes were considered "non-claims only," and these were included in the analysis. Crash and mileage data were provided per truck. Because the research team could not be certain that each driver remained with a particular vehicle in the pre-intervention and intervention phases, and because not all vehicles were represented in both phases, analysis did not focus on a paired comparison by vehicle. Instead, for each fleet, the distribution in crashes across pre-intervention and intervention phases was compared to the expected distribution of crashes, calculated using miles traveled per phase, assuming a binomial distribution.

Each crash was classified as "pre-intervention" (1) or "intervention" (0), based on the date the crash occurred. The sample proportion was calculated as shown in Figure 32:

$$\hat{p}(crash = 1) = \frac{number\ of\ pre - intervention\ crashes}{number\ of\ pre - intervention\ crashes + intervention\ crashes}$$

Figure 32. Equation. Model for calculating the proportion of crashes occurring in the pre-intervention versus intervention periods.

If crashes occurred randomly, without any effect of the OBMS, they would be expected to fall in either study phase proportional to the mileage of that study phase. For example, if a fleet had 50 percent of their total mileage during pre-intervention and 50 percent of their total mileage during intervention, the crashes would be expected to occur proportional to the mileage (50 percent of total crashes in pre-intervention and the remaining 50 percent in intervention), if no other factors were influencing the data. As shown in Figure 33, the null distribution used to compare the crash results was calculated from the mileage:

$$Expected\ p_0(crash = 1) = \frac{pre - intervention\ mileage}{pre - intervention\ mileage + intervention\ mileage}$$

Figure 33. Equation. Model for calculating null distribution to compare crash results.

A cumulative binomial distribution was used to calculate the probability of observing the sample crash proportion or greater, with the expected probability as calculated above. A probability of less than alpha ($\alpha = 0.05$ in all analyses presented here) indicates the distribution of crashes in

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[iii] Fleet-level criteria for crashes may differ. Not all crashes reported by fleets were U.S. Department of Transportation (USDOT) reportable.

study phases was likely not random. In this study, a significant result could signify the OBMS intervention had an effect on the crash rate.

Fleet crash rates for each phase were calculated per 1 million vehicle miles traveled (MVMT) Analysis was completed by individual fleet.

3.4.1 Fleet A

The data set for Fleet A included crash and mileage data from 68 study vehicles. The crash data set included 46 crashes from the pre-intervention stage and 82 crashes from the intervention stage. However, three of the pre-intervention stage crashes and two of the intervention stage crashes did not have vehicle data and were excluded from the data set. Of the crashes with vehicle data, 14 from the pre-intervention stage and 21 from the intervention stage were non-claims only. The 68 study vehicles traveled 2,692,435 miles during pre-intervention, an average of 39,595 miles per vehicle (SD = 10,153). The study vehicles traveled 2,685,379 miles during intervention, an average of 39,491miles per vehicle (SD = 10,536).

Fleet A had a pre-intervention rate of 5.2 non-claims-only crashes per MVMT and an intervention rate of 7.8 non-claims-only crashes per MVMT. The observed event rate change between intervention and pre-intervention was 50.4 percent. Pre-intervention events accounted for 40.0 percent of total events and pre-intervention mileage accounted for 50.1 percent of total mileage. The observed distribution of events by study phase was tested for significant difference from a null, expected distribution (calculated from the total mileage per study phase). Assuming the events follow a binomial distribution, the distribution of pre-intervention events was not significantly different than if distributed randomly ($p = 0.847$).

The Fleet A crash data included several other important variables about each crash. These variables were considered for additional analysis; however, several were associated with very small sample sizes. A total of 4 pre-intervention crashes and 12 intervention crashes were considered preventable and non-claims only. There were no crashes in the pre-intervention or intervention stages that had a reported injury (driver or other) or fatality. Crashes resulted in tickets in one pre-intervention stage crash and four intervention stage crashes. The pre-intervention stage and intervention stage each included two USDOT-reportable crashes.

3.4.2 Fleet E

The data set for Fleet E included crash and mileage data from 22 study vehicles. The crash data set included four crashes from the pre-intervention stage and three crashes from the intervention stage. All crashes in the data set were determined to be “non-claims-only” crashes. Pre-intervention crashes and mileage were collected from October 2012 to July 2013. Intervention crashes and mileage were collected from August 2013 to May 2014. Two vehicles had missing mileage data for one of the two study phases. The 21 study vehicles with mileage data for the pre-intervention phase traveled 972,608 miles total, or an average of 46,315 miles (SD = 33,635) per vehicle during pre-intervention. The 21 study vehicles with mileage data for the intervention phase traveled 662,762 miles total, or an average of 31,560 miles (SD = 15,033) per vehicle during intervention.

Fleet E had a pre-intervention rate of 4.1 non-claims-only crashes per MVMT and an intervention rate of 4.5 non-claims-only crashes per MVMT. The event rate difference between the intervention and pre-intervention phases was 10.1 percent. Pre-intervention events accounted for 57.1 percent of total events and pre-intervention mileage accounted for 59.5 percent of total mileage. Due to the low crash counts for both the pre-intervention and intervention study stages, the crash rate data were not tested for statistically significant differences.

The crash data included several other important variables about each crash. One of the seven crashes was an injury crash. There were no fatalities reported in any of the crashes. Six of the seven crashes were considered USDOT reportable (all four of the pre-intervention crashes and two of the intervention crashes).

3.4.3 Fleet H

The data set for Fleet H included crash and mileage data from 63 study vehicles. The crash data set included 52 crashes from the pre-intervention stage and 28 crashes from the intervention stage. Two crashes, both from the intervention stage, did not have vehicle data and were excluded from the data set. Of the remaining crashes, 23 were non-claims-only crashes in the pre-intervention period, and 15 were non-claims-only crashes in the intervention study period. Pre-intervention crashes and mileage were collected from January 31, 2013, to October 31, 2013, for 53 vehicles. Intervention crashes and mileage were collected from December 1, 2013, to August 31, 2014, for 47 vehicles. The 53 study vehicles with mileage data for the pre-intervention phase traveled 1,843,513 miles total, or an average of 34,783 miles (SD = 18,312) per vehicle during pre-intervention. The 47 study vehicles with mileage data for the intervention phase traveled 2,992,360 miles total, or an average of 63,667 miles (SD = 12,073) per vehicle during intervention.

Fleet H had a pre-intervention rate of 12.5 non-claims-only crashes per MVMT and an intervention rate of 5.0 non-claims-only crashes per MVMT. The observed event rate difference between the pre-intervention and intervention phases was 59.8 percent. Pre-intervention events accounted for 60.5 percent of total events and pre-intervention mileage accounted for 38.1 percent of total mileage. The observed distribution of events by study phase was tested for a significant difference from the null, expected distribution (calculated from the mileage per study phase). Assuming the events follow a binomial distribution, the distribution of events was significantly different than if distributed randomly ($p = 0.002$). The fleet experienced a significant decrease in events during intervention.

4. LESSONS LEARNED AND TECHNICAL CHALLENGES

There were challenges with implementation of the original study protocol. First, the same protocol could not be implemented for all sites or for all three phases. Hence, this study's findings do have limitations. There were differences in the timing of coaching events, as some safety supervisors provided feedback after much longer than expected time periods, while others were timelier in coaching. As expected, the initial models showed significant differences across the four fleets, which justified the need to examine the system's effectiveness using separate models.

There were also challenges with the data that were obtained from the system and with the type of exposure information provided by each carrier. These technical issues may have affected the conclusions drawn. Specific issues with Fleets D, E, and H are discussed below.

Fleet D

As shown in Figure 14, Fleet D experienced a higher rate of unfastened seatbelts from the study's inception, which could have been a result of combined technical issues, seasonal or temporary drivers, route stops at airport arrival or departure terminals, etc. Some fleets did not consistently or accurately provide driver identification information, resulting in a large number of unidentifiable drivers. For weeks 29–36, all recorded events were associated with unknown drivers and, as a result, no driver-level exposure data were available. Therefore, the event rate from these weeks could not be calculated. In February 2014, this fleet began using keypads to identify drivers. The number of unknown drivers returned to a normal level after implementation of this new identification tool. However, the rate of events associated with unfastened seatbelts remained at a high level.

Fleet E

Fleet E also experienced some issues with driver identification data collection. More specifically, no identifiable events were recorded by the OBMS from March 27–May 8, 2014 (about 6 weeks). Only four events were associated with identifiable drivers after this fleet entered the withdrawal phase on May 15, 2014. As of this writing, it is not clear to the study team why these difficulties existed; however, they limited the ability to analyze the withdrawal phase, as the event rate could not be computed without exposure data. Hence, the statistical analysis for Fleet E consisted of only the first 37 weeks.

Fleet H

Fleet H experienced issues from around week 2 until week 5. As noted earlier, HOS calculations that are computed using mileage data are more useful than those that are based on driver schedules. However, Fleet H had a large portion of mileage data that was not useable for weeks 2–5. Most of the events recorded during these weeks were based on the "YARD, MEN" category in the mileage data file. Yardmen are a group of mechanics (not drivers) and should not be included in the analysis. This resulted in a loss of exposure information from weeks 2–5. Although an adjustment was made based on driver schedule data for weeks 2–5, the HOS may not be as accurate. This may also explain why the event rates during the baseline phase were low, even close to zero, for these weeks (see Figure 13).

The instant driver feedback (IDF) light was not enabled for Fleet H until April 7, 2014 (week 23). As previously mentioned, the IDF lights provided drivers with instant feedback on their driving maneuvers. When an unsafe maneuver was detected, a yellow or red light, based on the severity of the maneuver, flashed for a few seconds. This issue with Fleet H indicates that feedback group drivers were not receiving any instant feedback during the first 18 weeks of their intervention phase. This may help to explain why their event rate kept increasing after the beginning of the intervention phase. It is interesting to note that the low-severity event rate of Fleet H began to decrease right after week 23 when the light was enabled (see Figure 14), which may indicate the immediate benefit of the instant feedback.

The control group for Fleet H always took the same routes; therefore, they were more familiar with the road environment (i.e., horizontal and vertical alignment of the roads, speed limits, and stop sign locations). This may partly explain why the control group in this fleet showed better performance than the feedback group.

5. STUDY SUMMARY AND FUTURE RESEARCH IMPLICATIONS

This study examined the effectiveness of the tested OBMS using driving performance data and information from questionnaires that assessed drivers' attitudes toward the system. The goal of the OBMS is to enhance driver performance via concurrent feedback (i.e., flashing feedback lights in vehicle) and cumulative feedback (i.e., coaching by safety managers). Summary statistics regarding the number of critical events, total event rate, and rate of events associated with the five most frequently observed behavior categories—speeding, unfastened seatbelts, distraction, fatigue, and stopping—were provided. Statistical models, including repeated measures ANOVA and cluster analysis, were also applied to help address the OBMS's effectiveness.

Data from two trucking fleets (A and H) and two motorcoach fleets (D and E) were analyzed. Based on the analysis, no consistent differences in terms of the effectiveness of the OBMS in reducing critical event rate were observed between trucking and motorcoach fleets (in general). However, safety performance of drivers did differ by fleet. Changes in the critical event rates over time were also different within trucking and motorcoach groups.

Generally, 95 percent of all recorded events were low-severity events and the remaining 5 percent were high-severity events. Fleet H, with more strict standards, tended to have more high-severity events than the three other fleets analyzed in this FOT, but the percentage of high-severity events in Fleet H was still much lower than low-severity events, comparatively.

Speeding accounted for about 80 percent of all events for Fleets A and E. The majority of events for Fleet D were associated with unfastened seatbelts (53 percent), but this may have been caused by the technical issue described previously instead of unsafe driving behaviors. The majority of events for Fleet H were associated with distraction (58 percent).

Mean event rate per driver per 100 HOS was calculated and plotted by fleets. Event rate did not change over time exactly as expected for all four fleets. For Fleet A, it decreased at the beginning of the intervention phase and remained at a low level thereafter. For Fleet E, the low-severity event rate showed a continually decreasing trend. The event rate in Fleet H typically increased until week 15 and then began to decrease. For Fleet D, the high-severity event rate decreased slightly when the intervention phase started, and stayed relatively stable until the end of the study when it started to increase. There was a lot of fluctuation in the low-severity event rates and any inferences that could be drawn are inconclusive. Control group drivers (receiving no feedback at any time) performed similarly to feedback group drivers in Fleet A and performed better than feedback group drivers in Fleet H. It should be noted that the control group was a smaller sample size (eight drivers in Fleet A and four in Fleet H) and was also probably biased toward the better drivers for these two fleets. Moreover, in Fleet H, control group drivers always took the same routes and were familiar with the road environment, which may also explain their lower rates.

Fleets A, D, and H had more middle-aged drivers (41–60 years old) while Fleet E tended to have older drivers (more than 60 years old). Performance of drivers in different age groups also differed by fleets. When considered and analyzed as a whole, event rates of drivers from different age groups changed similarly over time during the study period. Overall, young drivers (less than 40 years old) always had higher event rates than middle-aged and older drivers. Older drivers performed similarly to middle-aged drivers at the beginning of the study and always had lower event rates than middle-aged drivers starting after week 15.

Critical event rates aggregated by driver as well as by study group (i.e., feedback or control) and phase were heavily skewed toward zero, which means that many drivers did not have any dangerous behaviors captured by the system during certain phases of the study. A binary logit model was first used to examine whether drivers were more likely to engage in dangerous behaviors or not (critical event rate $\neq 0$ versus critical event rate $= 0$) given their fleet, study group, and the study phase. Repeated measures ANOVAs were applied to non-zero responses (critical event rate $\neq 0$) to model the SCE rates of drivers over the three study phases and two study groups while engaged in dangerous behaviors. A series of pairwise t-tests was also conducted to help gain greater insights on the model outcomes. It should be noted that since Fleet D experienced technical issues with the detection of seatbelts in the study, resulting in an abnormally large number of seatbelt events, an additional analysis was conducted for this fleet after removing this event type.

According to the binary logit model, for high- and low-severity events, drivers of both groups in Fleet A and Fleet H were equally likely to engage in dangerous behaviors in all three phases. A marginal significant phase effect was observed for low-severity events in Fleet D when events associated with seatbelts were removed, which suggests that drivers were 0.15 times less likely to engage in low-severity dangerous behaviors in the intervention phase. A significant phase effect was also observed for high-severity events in Fleet E, which suggests that drivers were 5.95 times more likely to engage in dangerous behaviors in the intervention phase.

Studying phase reveals a significant impact on event rate. Fleet A had significantly lower event rates for high- and low-severity events in the intervention phase than in the baseline phase, which suggests better safety performance after OBMS feedback was provided in the intervention phase. When feedback was removed in the withdrawal phase, the high-severity event rate increased somewhat, but still remained significantly lower than in the baseline phase. For low-severity events, the event rate in the withdrawal phase was even lower than in the intervention phase. For Fleet E, event rates in the intervention phase were significantly lower than in the baseline phase for both severity levels. For high-severity events, Fleet D had significantly lower event rates in the intervention phase. No significant differences were observed among phases for Fleet H. The impact of phase is different from the hypothesis for low-severity events in Fleet H and Fleet D (when analyzed with events associated with seatbelts). Event rates were significantly higher in the intervention phase for both fleets, which may be a consequence of the technical issues discussed earlier. For example, when events associated with seatbelts were removed, event rates in Fleet D did not differ significantly between the baseline and intervention phases.

With regard to study group, no significant differences were observed for Fleet A. For Fleet H, the effect of study group was marginally significant, suggesting lower event rates for control group drivers than feedback group drivers. As mentioned earlier, control group drivers in this fleet always took the same routes, which may have affected outcomes. Moreover, the control group was also likely biased toward the better drivers for these two fleets, which may partially explain these analysis results.

Findings presented at the driver-level were used to address the research questions related to driver performance and safety. Findings from the fleet-level analyses showed that high- and low-severity event rates dropped after the OBMS and feedback program was put in place for Fleets A, E, and H. The reductions were all significant at the 0.05 significance level. Although the event rate dropped significantly for high-severity events in Fleet D, a significant increase was observed for the low-severity events in this fleet. This is consistent with the conclusion based on driver-level approach and may also result from the high rate of seatbelt non-compliance, which happened from the onset of the study and quickly degenerated from the beginning of the intervention phase.

The fleet-level findings for Fleets A, D, and E regarding the effectiveness of the OBMS in reducing critical event rates corroborate those from the driver-level analysis. For Fleet H, there were different findings depending on the analysis. At the driver-level, Fleet H showed a significant increase in the intervention phase, but at the fleet-level, this fleet showed a significant decrease in the intervention phase. As noted earlier, the driver identification issues for Fleet H from weeks 2–5 resulted in a large number of events being associated with “yardmen,” which may be the reason why event rates during the baseline phase were low during this period. The fleet-level analysis includes unknown drivers (“yardmen” in this case) and more events and exposure data for the baseline phase.

In addition to the instant feedback provided by the in-vehicle OBMS, drivers also received coaching from safety managers to help improve their driving performance. Fleet managers typically pay more attention to more severe dangerous behaviors; thus, high-severity events were always coached. Fleet E provided much more timely coaching (about 90 percent of events were coached within 1 week) than the other three fleets, and also experienced the most notable decrease in its event rate, especially for low-severity events. Fleet H, with almost no coaching until week 15, also showed a corresponding increase in its event rate. Moreover, sporadic coaching—though it allowed larger numbers of events to be addressed at one time—appeared to be less effective than timely coaching.

Summary statistics were also calculated for the questionnaire data to determine how the attitudes of drivers toward the OBMS changed over time. Typically, drivers tended to have higher expectations of the OBMS in the pre-study and baseline questionnaires, but began to express more negative opinions after the interventions began. Interestingly, although their opinions were relatively the same during the entire intervention phase, they were most likely to lower their opinions again in the first month of the withdrawal phase. In spite of this, variation of the mean degree of agreement for each question was not high, ranging only from 0.83–1.61, which means that most drivers changed their opinions from “slightly agree” to “neutral” or from “neutral” to “slightly agree/disagree.”

The post-study questionnaire shows that control group drivers tended to have more positive attitudes towards the OBMS. Feedback group drivers typically still had positive opinions about the system. Drivers were most impressed that the system made them more aware of unsafe behaviors and helped them to improve their driving skills and drive more safely. Drivers who were not happy with the system mostly complained that it was distracting and not always operational.

To further assess the effects of the OBMS on fleet safety, an additional analysis was conducted using crash and mileage data collected by the fleets themselves. Three fleets provided their own collected crash and mileage data, for both the pre-intervention and intervention phases. The crash summaries were used to determine "non-claims-only" status for each crash. Crash rates per MVMT were calculated per fleet for each phase. Because the research team could not confirm that each driver remained with a particular vehicle in the pre-intervention and intervention phases, and because not all vehicles were represented in both phases, analysis did not focus on a paired comparison by vehicle. Instead, for each fleet, the pre-intervention and intervention period non-claims-only crash rates were compared for differences from the expected crash rates (based on mileage collected per phase) assuming a binomial probability distribution.

While one of the fleets had no statistically significant change between the pre-intervention phase and the intervention phase, one fleet did experience a statistically significant decrease in crash rate (12.5 crashes per MVMT in pre-intervention and 5.0 crashes per MVMT in intervention). It is important to note that, across all three fleets, a majority of vehicles did not experience a crash (80.28 percent of pre-intervention vehicles and 75.74 percent of intervention vehicles had zero crashes reported by their fleets).

The findings using fleet crash and mileage data support the findings using event-based data in the previous analyses of this report. The effectiveness of an OBMS appears to be affected by several different variables, which, due to differences in each fleet, can lead to inconsistent findings. Also, as shown in the calculations of crash rate by MVMT, crashes are rare events. The evaluation period for the OBMS was about 9 months. This study period may not have been long enough to capture a significant change in crash occurrence. However, the hypothesis and analysis were important in providing another method of assessing OBMS efficacy—especially in a way that fleets might measure it themselves. Fleets using an OBMS have to rely on their own crash data (before and after system deployment) to see if the system has affected fleet safety.

Limitations associated with this fleet-provided crash data analysis include having a limited sample of fleets and being unable to make direct paired comparisons for drivers in the pre-intervention and intervention phases. Also, due to the self-report nature of the fleet-owned crash data, the crash data may contain inaccuracies or be incomplete. Assessing OBMS efficacy using fleet crash data is an important analysis method to continue to investigate. Though the one significant finding in this analysis showed a crash reduction benefit of 59.8 percent, a recommendation for a future study is to use a longer evaluation period, which may more clearly reveal the benefits of the OBMS with respect to crash mitigation.

Six research questions were examined over the course of this study:

1. Does individual driving performance (e.g., braking, distraction) improve over time with OBMS feedback?

   ANSWER: There were no significant differences in terms of mean event rate per driver between the control and feedback groups in Fleet A, and the event rate of control group drivers in Fleet H was even lower than that of feedback group drivers. However, only 2 fleets included a control group and the sample size for this group was quite small (10 drivers in Fleet A and 4 in Fleet H). Also, control group driver selection was probably biased toward better drivers. However, there were differences noted between the intervention period and the baseline and withdrawal periods in most cases for all four fleets. In general, the event rate did decrease over time, and this could be because of the feedback provided by the OBMS in addition to the coaching. The use of the system over time may have enhanced the safety culture over time, which could have led to a reduction in the event rate for both the feedback and control groups.

2. Does the OBMS (with feedback program) improve safety (e.g., reduce the number of SCEs)?

   ANSWER: The OBMS does improve safety for most fleets. More specifically, for Fleets A and E, the high- and low-severity event rates dropped significantly in the intervention phase when compared to the baseline phase. There was also a significantly lower number of high-severity events in the intervention phase when compared to the baseline phase for Fleets D and H.

3. If driving performance improves, does the improvement persist?

   ANSWER: The improvement did persist for Fleet A. With respect to the low-severity event rates, the withdrawal phase showed much lower numbers than the intervention phase. And both the intervention and withdrawal phases were significantly lower than the baseline phase. For high-severity events, although the event rate in the withdrawal phase was higher than that in the intervention phase, it was still significantly lower than the baseline phase. Hence, these outcomes demonstrate that improvement in Fleet A persisted even after the interventions were removed.

4. How do the drivers' attitudes toward the OBMS and feedback program change over time?

   ANSWER: Drivers' attitudes toward the OBMS were mixed. In the pre-study questionnaire, all drivers reported that their feelings were "neutral" or that they "slight agreed" that there were benefits to using an OBMS. Drivers' opinions about the system tended to go down once the intervention phase began. Despite that, they still felt there were benefits to the system. Cluster analysis revealed four groups of drivers: those who were fairly satisfied with the system throughout the study, those who were not, those who had lower expectations initially, and those who had greater expectations initially.

5. What are the fleet safety supervisors' attitudes toward the OBMS?

   ANSWER: Fleet safety supervisors had more positive opinions about the OBMS than the drivers. Their attitudes were fairly consistent from the start to the end of the study. They tended to agree that there were benefits to using the OBMS, and they typically disagreed or slightly disagreed that the system, along with the feedback and coaching, was distracting or annoying.

6. Does the OBMS (with feedback program) reduce crash rates?

   ANSWER: Though not statistically significant, mean crash rates per vehicle per 10,000 miles of driving in Fleet A increased from the baseline to the intervention phase, while the mean crash rates in Fleet H decreased, which was statistically significant. The inconsistent findings between the two fleets may be due to differences in each fleet, as well as the small sample size of crashes (as crashes are very rare).

Following are several recommendations:

- Judging by the effectiveness of efficient and timely coaching, the research team recommends that safety managers coach events on a timelier basis.
- Periodic OBMS training is recommended to ensure that drivers understand the system. In this study, only handbooks with pictures and descriptions of the system were distributed to the drivers. Although most drivers noted it was not difficult to understand the system, some commented that the instant feedback lights confused them. Drivers who do not understand the system cannot benefit from the OBMS's instant feedback and may potentially be distracted by the feedback lights, as well.
- As for the OBMS device, the research team would recommend using auditory alerts instead of flashing lights to provide instant feedback. Instant feedback aims to provide drivers immediate alerts in response to their dangerous driving behaviors. However, drivers are focusing on the road when driving, and thus often do not immediately notice the visual cues provided by the flashing lights on the OBMS's front camera when a driving error is made. In addition, if the instant feedback must be checked frequently, as many drivers commented in the questionnaire, it will ultimately be distracting. Using auditory alerts will provide drivers instant feedback without requiring them to look off the road.
- The research team would recommend adjusting the system to be less sensitive in providing instant feedback. Sensitive systems tend to provide instant feedback more frequently, which some drivers complained was annoying and distracting. This issue may be more severe if auditory alerts are used as well.
- For future research examining OBMS feedback, the research team would recommend a larger control group sample size with relatively similar pre-study safety performance to that of the feedback group. This may help to control the differences in OBMS feedback in these two groups and therefore provide more insight into the effectiveness of OBMS feedback in reducing dangerous driver behaviors.
- For future research, additional analyses can be conducted to examine the impact of environmental factors and the different levels of data collection. For example, a random coefficients modeling approach is a common approach for analyzing longitudinal data.[23] Using this model, one can consider the impact of fleet, group, and phase (OBMS feedback), as well as the environmental and demographic factors. The environmental factors can include light conditions, roadway type, and weather conditions. However, the OBMS does not automatically parse out the data by these factors, so manual reduction

will be needed. Additional demographic information would include driver age, driver gender, years of driving, etc.

- Assessing OBMS efficacy using fleet crash data is an important analysis method that warrants further study. This study was limited by the small sample size of fleets and being unable to make direct paired comparisons for drivers in the pre-intervention and intervention phases. Also, due to the self-report nature of fleet-owned crash data, the crash data may contain inaccuracies or be incomplete. Recommendations for future studies include using a longer evaluation period, which may more clearly reveal the benefits of OBMS use with respect to crash mitigation.

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APPENDIX A: DRIVER BASELINE QUESTIONNAIRE

Please answer the following questions **based on what you think the system will be like.** To answer, **check only one box** for each statement that best expresses your answer. The questionnaire will take about 15 minutes to complete.

General Use of SmartDrive

1. I think using the SmartDrive system will…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … make it easier to drive	☐	☐	☐	☐	☐	☐	☐
c) … make me more aware of my surroundings (other vehicles, lane position, etc.)	☐	☐	☐	☐	☐	☐	☐
d) … reduce distractions	☐	☐	☐	☐	☐	☐	☐
e) … improve my driving skills	☐	☐	☐	☐	☐	☐	☐

2. I think the SmartDrive system will be *useful* (e.g., improves safety, reduces speeding, reduces distraction, etc.) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/Residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/Freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

3. I think the SmartDrive system will be…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … easy to understand	☐	☐	☐	☐	☐	☐	☐
b) … annoying	☐	☐	☐	☐	☐	☐	☐
c) … distracting	☐	☐	☐	☐	☐	☐	☐

4. I will trust the feedback provided by the SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

5. I think I can depend on the feedback from the OBMS.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Instant Feedback

The SmartDrive system provides instant feedback that tells you when there is an unsafe maneuver. When an unsafe maneuver is detected (e.g., hard braking), a yellow or red light (based on the severity of the maneuver) will flash for a few seconds.

6. Please indicate how useful (e.g., help avoid a crash) the **instant feedback** will be in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

7. The **instant feedback** will…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improve my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … make it easier to drive	☐	☐	☐	☐	☐	☐	☐
d) … be distracting	☐	☐	☐	☐	☐	☐	☐
e) … be annoying	☐	☐	☐	☐	☐	☐	☐

Cumulative Feedback

The SmartDrive system provides cumulative feedback on your safety performance. A solid green, yellow, or red light will indicate your safety score during the trip. The solid green light indicates MOST safe, and red indicates LEAST safe. Your goal is to maintain a green light for the entire trip.

8. The **cumulative feedback** will...

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improve my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … be distracting	☐	☐	☐	☐	☐	☐	☐
d) … be annoying	☐	☐	☐	☐	☐	☐	☐

Safety Manager Coaching

The SmartDrive system records unsafe maneuvers (including videos), which will be sent to your safety manager for coaching. Your safety manager will review the recorded events and conduct individual coaching sessions with you as necessary.

9. The **safety manager coaching** will…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improve my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … invade my privacy	☐	☐	☐	☐	☐	☐	☐
d) … be annoying	☐	☐	☐	☐	☐	☐	☐

Other Comments about SmartDrive

1. If I had a choice, I would drive a commercial vehicle equipped with a SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

2. With a SmartDrive system, I adjust my driving to the feedback it provides.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

3. I would recommend the SmartDrive system to other commercial vehicle drivers.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

4. I think being monitored by the SmartDrive system is an invasion of my privacy.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

5. I think sharing my driving data with my safety supervisor is an invasion of my privacy.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

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APPENDIX B: DRIVER QUESTIONNAIRE WITH OBMS FEEDBACK

Please answer the following questions about the OBMS. Please **check only one** box for each statement. The questionnaire will take about 15 minutes to complete.

General Use of SmartDrive

1. Using the SmartDrive system…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … makes me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … makes it easier to drive	☐	☐	☐	☐	☐	☐	☐
c) … makes me more aware of my surroundings (other vehicles, lane position, etc.)	☐	☐	☐	☐	☐	☐	☐
d) … reduces distractions	☐	☐	☐	☐	☐	☐	☐
e) … improves my driving skills	☐	☐	☐	☐	☐	☐	☐

2. The SmartDrive system is *useful* (e.g., improves safety, reduces speeding, reduces distraction) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/Residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/Freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

3. The SmartDrive system is…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … easy to understand	☐	☐	☐	☐	☐	☐	☐
b) … annoying	☐	☐	☐	☐	☐	☐	☐
c) … distracting	☐	☐	☐	☐	☐	☐	☐

4. I trust the feedback provided by the SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

5. I can depend on the feedback from the SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Instant Feedback

The SmartDrive system provides instant feedback that informs you of unsafe maneuvers (e.g., hard braking). When an unsafe maneuver is detected, a yellow or red light (based on the severity of the maneuver) will flash for a few seconds.

6. The **instant feedback** is *useful* (e.g., helpful in avoiding collisions) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

7. The **instant feedback**…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … makes me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improves my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … makes it easier to drive	☐	☐	☐	☐	☐	☐	☐
d) … is distracting	☐	☐	☐	☐	☐	☐	☐
e) … is annoying	☐	☐	☐	☐	☐	☐	☐

Cumulative Feedback

The SmartDrive system provides you cumulative feedback on your overall drive performance. A solid green, yellow, or red light will indicate your safety score during the trip. The solid green light indicates MOST safe, and red indicates LEAST safe. Your goal is to maintain a green light for the entire trip.

8. The **cumulative feedback** ...

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … makes me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improves my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … is distracting	☐	☐	☐	☐	☐	☐	☐
d) … is annoying	☐	☐	☐	☐	☐	☐	☐

Safety Manager Coaching

The SmartDrive system records unsafe maneuvers (including videos), which will be sent to your safety manager for coaching. Your safety manager reviews the recorded events and conducts individual coaching sessions with you as necessary.

9. The **safety manager coaching**…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … makes me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improves my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … invades my privacy	☐	☐	☐	☐	☐	☐	☐
d) … is annoying	☐	☐	☐	☐	☐	☐	☐

Other Comments about SmartDrive

10. If I had a choice, I would drive a commercial vehicle equipped with a SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

11. With a SmartDrive system, I adjust my driving to the feedback it provides.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

12. I would recommend the SmartDrive system to other commercial vehicle drivers.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

13. I think being monitored by the SmartDrive system is an invasion of my privacy.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

14. I think sharing my driving data with my safety supervisor is an invasion of my privacy.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

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APPENDIX C: DRIVER QUESTIONNAIRE AFTER OBMS FEEDBACK WAS REMOVED

Please answer the following questions based on **your experience of past use of** the SmartDrive system. You need to **check only one box** for each statement. It will take about 15 minutes to finish the questionnaire.

General Use of SmartDrive

1. Using the SmartDrive system …

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … made it easier to drive	☐	☐	☐	☐	☐	☐	☐
c) … made me more aware of my surroundings (other vehicles, lane position, etc.)	☐	☐	☐	☐	☐	☐	☐
d) … reduced distractions	☐	☐	☐	☐	☐	☐	☐
e) … improved my driving skills	☐	☐	☐	☐	☐	☐	☐

2. The SmartDrive system was *useful* (e.g., improves safety, reduces speeding events, reduces distraction, etc.) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/Residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/Freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

3. The SmartDrive system was…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … easy to understand	☐	☐	☐	☐	☐	☐	☐
b) … annoying	☐	☐	☐	☐	☐	☐	☐
c) … distracting	☐	☐	☐	☐	☐	☐	☐

4. I trusted the feedback provided by the SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

5. I depended on the feedback from the SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Instant Feedback

The SmartDrive system provided instant feedback that informed you of unsafe maneuvers. When an unsafe maneuver (e.g., hard braking) was detected, a yellow or red light (based on the severity of the maneuver) flashed for a few seconds.

6. The **instant feedback** was *useful* (for example, helpful in avoiding collisions) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

7. The **instant feedback**…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improved my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … made it easier to drive	☐	☐	☐	☐	☐	☐	☐
d) … was distracting	☐	☐	☐	☐	☐	☐	☐
e) … was annoying	☐	☐	☐	☐	☐	☐	☐

Cumulative Feedback

The SmartDrive system provides you cumulative feedback on your overall drive performance. A solid green, yellow, or red light will indicate your safety score during the trip. The solid green light indicates MOST safe, and red indicates LEAST safe. Your goal is to maintain a green light for the entire trip.

8. The **cumulative feedback** ...

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improved my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … was distracting	☐	☐	☐	☐	☐	☐	☐
d) … was annoying	☐	☐	☐	☐	☐	☐	☐

Safety Manager Coaching

The SmartDrive system records unsafe maneuvers (including videos), which were sent to your safety manager for coaching. Your safety manager reviewed the recorded events and conducted individual coaching sessions with you as necessary.

9. The **safety manager coaching**…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made me a safer driver	☐	☐	☐	☐	☐	☐	☐
b) … improved my driving skills	☐	☐	☐	☐	☐	☐	☐
c) … invaded my privacy	☐	☐	☐	☐	☐	☐	☐
d) … was annoying	☐	☐	☐	☐	☐	☐	☐

Other Comments about SmartDrive

10. If I had a choice, I would drive a commercial vehicle equipped with a SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

11. With a SmartDrive system, I adjust my driving to the feedback it provides.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

12. I would recommend the SmartDrive system to other commercial vehicle drivers.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

13. I think being monitored by the SmartDrive system is an invasion of my privacy.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

14. I think sharing my driving data with my safety supervisor is an invasion of my privacy.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

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APPENDIX D: PRE-STUDY QUESTIONNAIRE FOR SAFETY MANAGERS

Please answer the following questions **based on what you think the SmartDrive system will be like** for your drivers**.** To answer, **check only one box** for each statement that best expresses your answer (unless indicated otherwise). The questionnaire will take about 15 minutes to complete.

General Use of SmartDrive

1. I think using the SmartDrive system will …

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … make it easier to drive	☐	☐	☐	☐	☐	☐	☐
c) … make drivers more aware of the surroundings (other vehicles, lane position, etc.)	☐	☐	☐	☐	☐	☐	☐
d) … reduce distractions	☐	☐	☐	☐	☐	☐	☐
e) … improve drivers' driving skills	☐	☐	☐	☐	☐	☐	☐

2. I think the SmartDrive system will be *useful* for drivers (e.g., improves safety, reduces speeding events, reduces distraction, etc.) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/Residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/Freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

3. I think the SmartDrive system will be…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … easy to understand	☐	☐	☐	☐	☐	☐	☐
b) … annoying	☐	☐	☐	☐	☐	☐	☐
c) … distracting	☐	☐	☐	☐	☐	☐	☐

4. I will trust the feedback provided by the SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Instant Feedback

The SmartDrive system provides instant feedback that tells your drivers when there is an unsafe maneuver. When an unsafe maneuver is detected (e.g., hard braking), a yellow or red light (based on the severity of the maneuver) will flash for a few seconds.

5. The **instant feedback** will be *useful* for drivers (for example, helpful in avoiding collisions) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

6. The **instant feedback** will…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … improve drivers driving skills	☐	☐	☐	☐	☐	☐	☐
c) … make it easier to drive	☐	☐	☐	☐	☐	☐	☐
d) … be distracting	☐	☐	☐	☐	☐	☐	☐
e) … be annoying	☐	☐	☐	☐	☐	☐	☐

Cumulative Feedback

The SmartDrive system provides cumulative feedback on your drivers' safety performance. A solid green, yellow, or red light will indicate their safety score during the trip. The solid green light indicates MOST safe, and red indicates LEAST safe. Drivers' goal is to maintain a green light for the entire trip.

7. The **cumulative feedback** will...

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … improve drivers' driving skills	☐	☐	☐	☐	☐	☐	☐
c) … be distracting	☐	☐	☐	☐	☐	☐	☐
d) … be annoying	☐	☐	☐	☐	☐	☐	☐

Safety Manager Coaching

The SmartDrive system records unsafe maneuvers (including videos), which will be sent to you for coaching. You will review the recorded events and conduct individual coaching sessions with your drivers as necessary.

8. The **safety manager coaching** will…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … make drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … improve drivers' driving skills	☐	☐	☐	☐	☐	☐	☐

Other Comments about SmartDrive

9. I feel it would be useful to install SmartDrive systems as standard equipment in commercial vehicles.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

10. I think the SmartDrive system will improve the overall commercial vehicle driver's safety.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

11. I would recommend the SmartDrive system to my friends or colleagues.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

12. I would recommend the company to install SmartDrive systems for all commercial vehicles in the future as standard equipment.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

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APPENDIX E: POST-STUDY QUESTIONNAIRE FOR SAFETY MANAGERS

Please answer the following questions based on your experience with your drivers using the SmartDrive onboard monitoring system. To answer, **check only one box** for each statement that best expresses your answer (unless indicated otherwise). The questionnaire will take about 15 minutes to complete.

General Use of SmartDrive

1. Using the SmartDrive system…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … made it easier to drive	☐	☐	☐	☐	☐	☐	☐
c) … made drivers more aware of the surroundings (other vehicles, lane position, etc.)	☐	☐	☐	☐	☐	☐	☐
d) … reduced distractions	☐	☐	☐	☐	☐	☐	☐
e) … improved drivers' driving skills	☐	☐	☐	☐	☐	☐	☐

2. The SmartDrive system was *useful* for drivers (e.g., improves safety, reduces speeding events, reduces distraction, etc.) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/Residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/Freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

3. The SmartDrive system was…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … easy to understand	☐	☐	☐	☐	☐	☐	☐
b) … annoying	☐	☐	☐	☐	☐	☐	☐
c) … distracting	☐	☐	☐	☐	☐	☐	☐

4. I trusted the feedback provided by the SmartDrive system.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Instant Feedback

The SmartDrive system provides instant feedback that tells your drivers when there is an unsafe maneuver. When an unsafe maneuver is detected (e.g., hard braking), a yellow or red light (based on the severity of the maneuver) will flash for a few seconds.

5. The **instant feedback** was *useful* for drivers (for example, helpful in avoiding collisions) in the following situations:

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) Local/residential road	☐	☐	☐	☐	☐	☐	☐
b) Highway/freeway	☐	☐	☐	☐	☐	☐	☐
c) Good weather	☐	☐	☐	☐	☐	☐	☐
d) Bad weather	☐	☐	☐	☐	☐	☐	☐
e) Daytime	☐	☐	☐	☐	☐	☐	☐
f) Nighttime	☐	☐	☐	☐	☐	☐	☐

6. The **instant feedback** …

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … improved drivers driving skills	☐	☐	☐	☐	☐	☐	☐
c) … made it easier to drive	☐	☐	☐	☐	☐	☐	☐
d) … was distracting	☐	☐	☐	☐	☐	☐	☐
e) … was annoying	☐	☐	☐	☐	☐	☐	☐

Cumulative Feedback

The SmartDrive system provides cumulative feedback on your drivers' safety performance. A solid green, yellow, or red light will indicate their safety score during the trip. The solid green light indicates MOST safe, and red indicates LEAST safe. Drivers' goal is to maintain a green light for the entire trip.

7. The **cumulative feedback** ...

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … improved drivers' driving skills	☐	☐	☐	☐	☐	☐	☐
c) … was distracting	☐	☐	☐	☐	☐	☐	☐
d) … was annoying	☐	☐	☐	☐	☐	☐	☐

Safety Manager Coaching

The SmartDrive system records unsafe maneuvers (including videos), which were sent to you for coaching. You reviewed the recorded events and conducted individual coaching sessions with your drivers as necessary.

8. The **safety manager coaching**…

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
a) … made drivers safer	☐	☐	☐	☐	☐	☐	☐
b) … improved drivers' driving skills	☐	☐	☐	☐	☐	☐	☐

Other Comments about SmartDrive

9. I feel it would be useful to install SmartDrive systems as standard equipment in commercial vehicles.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

10. I think the SmartDrive system will improve the overall commercial vehicle driver's safety.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

11. I would recommend the SmartDrive system to my friends or colleagues.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

12. I would recommend the company to install SmartDrive systems for all commercial vehicles in the future as standard equipment.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

A Little about You

13. How many years have you been with the company? _____________ years   ____________ months

14. How long have you been a safety supervisor with this company? _________ years ________ months

15. How many drivers did you supervise/coach in the past month? __________ drivers

APPENDIX F: DAS DATA DICTIONARY

LIST OF VARIABLES

The following variables are included in the text files.

Table 12. Variables included in the text files.

Variable #	Name
1	Trip identifier
2	Sync
3	Time
4	Gas Pedal Position
5	Speed, vehicle network
6	Speed, GPS horizontal
7	Yaw rate
8	Heading, GPS
9	Lateral acceleration
10	Longitudinal acceleration
11	Lane markings, Continuity, Left Side Left Lane
12	Lane markings, Continuity, Right Side Left Lane
13	Lane markings, Continuity, Left Side Right Lane
14	Lane markings, Continuity, Right Side Right Lane
15	Lane markings, distance left
16	Lane markings, distance right
17	Lane markings, type left
18	Lane markings, type right
19	Lane markings, probability left
20	Lane markings, probability right
21	Radar, forward, ID
22	Radar, forward, range
23	Radar, forward, range rate
24	Radar, forward azimuth
25	Light intensity
26	Brake on off
27	Turn signal state

Table 13. Data dictionary entries.

#	Variable	Column	Units	Approx. Data Rate	Sign Convention and Coding	Notes
1	Trip identifier	1	-	-		
2	Sync	2	-	10 Hz		Increasing integer for each row of data within a file
3	Time	3	ms	10 Hz		
4	Gas Pedal Position	4	-	3-10 Hz	Increasing value indicates increasing deflection	
5	Speed, vehicle network	5	km/h	3-10 Hz	Forward and reverse motions are positive	
6	Speed, GPS horizontal	6	km/h	1 Hz	Forward and reverse motions are positive	
7	Yaw rate	7	deg/s	10 Hz	Positive if vehicle turns to the right.	
8	Heading, GPS	8	deg	1 Hz	0 - 359, 0 = North, 90 = East, 180 = South, 270 = West	
9	Lateral acceleration	9	g	10 Hz	Positive indicates lateral acceleration as generated by the vehicle turning to the right.	
10	Longitudinal acceleration	10	g	10 Hz	Positive indicates longitudinal acceleration as generated by the vehicle accelerating from a stop.	
11	Lane markings, Continuity, Left Side Left Lane	11	-	10 Hz	0 = solid, 1 = dash, 2 = unsure	
12	Lane markings, Continuity, Right Side Left Lane	12	-	10 Hz	0 = solid, 1 = dash, 2 = unsure	
13	Lane markings, Continuity, Left Side Right Lane	13	-	10 Hz	0 = solid, 1 = dash, 2 = unsure	

#	Variable	Column	Units	Approx. Data Rate	Sign Convention and Coding	Notes
14	Lane markings, Continuity, Right Side Right Lane	14	-	10 Hz	0 = solid, 1 = dash, 2 = unsure	
15	Lane markings, distance left	15	in.	10 Hz	Negative normal condition. Movement left in lane increases value toward zero. Positive when camera center line crosses left marker.	
16	Lane markings, distance right	16	in.	10 Hz	Positive normal condition. Movement right in lane reduces value toward zero. Negative when camera center line crosses right marker.	
17	Lane markings, type left	17	-	10 Hz	0 = none, 1 = double line, 2 = single line, 3 = road gutter, 4 = road edge	
18	Lane markings, type right	18	-	10 Hz	0 = none, 1 = double line, 2 = single line, 3 = road gutter, 4 = road edge	
19	Lane markings, probability left	19	-	10 Hz		
20	Lane markings, probability right	20	-	10 Hz		
21	Radar, forward, ID	21-27	-	10 Hz	Cycles 1 through 255 as new targets are identified.	Target ID provided for seven potential physical targets. Over time, same target may appear in any or one of the seven columns
22	Radar, forward, range	28-34	ft.	10 Hz		Range to seven potential targets. Use Radar, forward ID columns to identify which column to query for a given target's range.

#	Variable	Column	Units	Approx. Data Rate	Sign Convention and Coding	Notes
23	Radar, forward, range rate	35-41	ft./s	10 Hz	Positive values indicate distance to target increasing	Range rate to seven potential targets. Use Radar, forward ID columns to identify which column to query for a given target's range rate.
24	Radar, forward azimuth	42-48	rads	10 Hz	Positive value to right (passenger side) of forward facing radar center line.	Azimuth to seven potential targets. Use Radar, forward ID columns to identify which column to query for a given target's azimuth.
25	Light intensity	49	Lux	10 Hz	Increasing value indicates increasing light intensity from either natural or manufactured sources (e.g., headlamps, overhead lighting). Only appropriate as delivered for detecting trend in light intensity within one file at night. Scale not equal across vehicles and/or trips.	
26	Brake on off	50	-	10 Hz	0 = off, 1 = on	
27	Turn signal state	51	-	10 Hz	0 = off, 1 = left, 2 = right, 3 = both	

APPENDIX G: INFORMED CONSENT FORM FOR TRUCK DRIVERS

VIRGINIA TECH

Informed Consent for Participants in Research Projects Involving Human Participants

Truck Drivers

Title of Project: Onboard Monitoring System Field Operational Test

Investigators: Richard Hanowski, Darrell Bowman, and Rebecca Olson

I. Purpose of this Research/Project

The main purpose of this study is to collect up to 12 months of continuous video and vehicle sensor data from 250 commercial vehicles. In addition, we will also be accessing your CDL driving record from the time you obtained your CDL until the end of your participation time in this study. This is being done in order to understand driver behavior and driving patterns. Data from this study will be used in a confidential way to understand commercial vehicle driving. This Informed Consent Form is to explain your role in this study.

II. Procedures

If you agree to participate in this study, you will be asked to do the following:

1. Read and sign this Informed Consent Form.
2. Allow an experimenter to photocopy or make a digital copy of your valid Class-A commercial driver's license – this information will be used to access your CDL driving records from the time you obtained your CDL until the end of your participation time.
3. Allow an experimenter to take a digital photo of your face – this will be used to identify you as the correct participant when looking at the video data.
4. Drive an instrumented vehicle for up to 12 months on your normal route(s). The vehicle instrumentation includes videotaping you (driver's seat only, does not include passenger seat or Sleeper Berth) at all times when the vehicle is on and in motion. The vehicle instrumentation also includes collecting data from the truck such as how hard you brake, your speed, forward radar, etc.
5. Fill out a brief questionnaire once a month and participate in a verbal exit interview at the end of your participation.
6. Allow us to potentially use short (approximately 30 seconds) video clips of you performing various behaviors for research-related presentations.
7. Allow us to access your vehicle every 2 to 3 weeks in order to swap out the hard drive containing the data. This process will involve you meeting with a study experimenter at your carrier's local maintenance shop, parking lot, or fueling station. The experimenter will be monitoring the capacity of the hard drive and make arrangements to meet with you the next time you are at the fleet location to swap out the hard drive. The entire hard drive swap process should take approximately five minutes.

8. You will be contacted at the end of this study to ask if you would be willing to release your video data for training and educational purposes. At that time, you will also be asked if we may contact you in the future regarding the data collected during this study.

For this study we will be collecting data from approximately 500 commercial-vehicle drivers like you. In addition to the continuous video and vehicle data described above, we will also ask you to fill out a brief questionnaire once a month. The starting day of data collection is determined by the date when you start driving an instrumented vehicle.

III. Risks and Discomforts

There are some risks and discomforts to which you may be exposed to in volunteering for this research. These risks include:

1. The risk of a crash associated with driving a commercial vehicle as you usually do.
2. The risk of filling out the questionnaires is minimal and similar to completing office paperwork.
3. Stress associated with being continuously recorded while driving (the video will show your face, a forward view, an over-the-shoulder view, side view, and your actions in response to the driving situation).
4. In most cases, placing the data collection system in the vehicle will not affect the operating or handling characteristics of the vehicle. However, in some cases, the electromagnetic signals generated by the data collection system may cause interference with the vehicle’s radio. If this happens in your vehicle and is of concern to you, please contact us directly and we will resolve this issue to the best of our ability.
5. If you drive into an area where cameras are not allowed, including international border crossings, certain military and intelligence locations, and certain manufacturing facilities, there is a risk that you may be detained or arrested or that your vehicle may be impounded.
6. There is an additional risk not encountered in everyday driving. While you are driving the instrumented vehicle, cameras will record continuous video of you, your actions, and surrounding traffic. In the event of an accident, there is a risk that the video and vehicle parametric data could be obtained in conjunction with a government inquiry, or in litigation or dispute resolution. However, under normal circumstances your identity and the company you work for will be kept confidential.

The following precautions will be taken to ensure minimal risk to the participants:

1. You will be instructed to follow your company’s safety protocol.
2. Your participation in (or withdrawal from) this study does not have any influence on your status as an employee with your current company. However, it should be made clear that while the OBMS will be installed in your vehicle per company policy, your participation in the current study only involves allowing VTTI to collect continuous video and sensor data while your vehicle is on and in motion.
3. All data collection equipment will be mounted such that, to the greatest extent possible, it will not pose a hazard in any foreseeable way. Larger equipment will be mounted away from the cab occupants and rigidly fastened to the cab structure.

IV. Benefits

No promise or guarantee of benefits is being made to encourage you to participate. Past experiences with similar studies, involving heavy-vehicle drivers, indicate that you may find the study interesting.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participating, your name and the company you work for will be separated from the data and replaced with a number. That is, your data will not be attached to your name, but rather to a number (e.g., Driver 001, Location A). It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

While you are driving the vehicle, a camera will continuously videotape your face and other areas from five different angles: forward roadway, face view, over-the-shoulder, right-side of vehicle, and left-side of vehicle. An example is shown below. All continuous video and other data from this study will be stored in a secured area at Virginia Tech. Access to the continuous digital video files will be under the supervision of the Principal Investigator and lead VTTI researchers involved in the project. All data will be encrypted at the time of data collection and will be decrypted only for approved analyses.

One set of data will be permanently housed at Virginia Tech under the supervision of the Virginia Tech Transportation Institute, the organization overseeing the data collection for the entire study. It is possible that, after data collection is complete one copy of study data will be transferred to the U.S. Department of Transportation and/or other secure locations as directed by the U.S. Department of Transportation or the Virginia Tech Transportation Institute for permanent storage and oversight.

Authorized project personnel, authorized employees of the research sponsors, and authorized VTTI and research sponsor subcontractors will have access to continuous study data that personally identifies you or that could be used to personally identify you. As explained below, other qualified research partners may be given limited access to your driver data, vehicle data, driving data, and additional crash data, solely for authorized research purposes and with the consent of an IRB. This limited access will be under the terms of a data sharing agreement or contract that, at a minimum, provides you with the same level of confidentiality and protection provided by this Consent Form. However, even these qualified researchers will not be permitted to copy raw study data that identifies you, or that could be used to identify you, or to remove it from the secure facilities in which it is stored without your consent.

It is expected that the data we capture throughout the course of the entire study, including that from all the approximately 500 participants, will be a valuable source of data on how drivers respond to certain situations and how the roadway and vehicle might be enhanced to improve driver safety. Researchers who study traffic congestion and traffic patterns may also find the data useful. Therefore, it is expected that there will be follow-on data analyses using all or part of the data for up to 30 years into the future. These follow-on analyses will be conducted by qualified researchers with IRB approval, as required by law, who may or may not be part of the original study team. In consenting to this study, you are consenting to future research uses of the information and videos we gather from you, consistent with the protections described above and elsewhere in this document.

If you are involved in a crash while participating in this study, the data collection equipment in your vehicle will likely capture the events leading up to the event. You are under NO LEGAL OBLIGATION to voluntarily mention the data collection equipment or your participation in this study at the time of a crash or traffic offense.

We will do everything we can to keep others from learning about your participation in the research. We may disclose information about you as required by law, in conjunction with a government inquiry, or in litigation or dispute resolution. You should understand that this informed consent does not prevent you or a member of your family from voluntarily releasing information about yourself or your involvement in this research.

This Informed Consent Form does not prevent the researchers from disclosing voluntarily matters such as child abuse, or subject's threatened or actual harm to self or others. This could also include behaviors such as habitually driving under the influence of drugs or alcohol, allowing an unlicensed minor to drive the vehicle. If this type of behavior is observed, we reserve the right to remove you from the study and inform the appropriate authorities of what we have observed. In most cases, we will notify you first of the behaviors we have observed prior to removing you from the study or informing others of our observations. If you are removed from the study, your compensation will be prorated based on the time you have already spent as a participant in the study.

In addition, at the end of your participation time, you will be asked to sign an optional additional form asking for your permission to release your data for training and/or educational purposes.

Your choice of whether or not to allow your data to be used in this manner will have no effect on your participation in this study or on your employment.

VI. Compensation

You will receive $100 as a sign-up bonus for agreeing to participate in this study. You will also receive $50 a month for every questionnaire that you fill out. You will also receive a $300 bonus if you fill out all required questionnaires and participate in the study for the full 12 months. Finally, you will receive a Satellite radio installed in your truck and a one-year subscription to Sirius XM.

If you elect to withdraw from the study or if your employment is terminated, you will be compensated for the questionnaires you have completed up to that time. The Satellite radio will remain in your truck for up to one year, or until the VTTI DAS is removed, whichever comes first.

VII. Freedom to Withdraw

Participation in this research is voluntary. You are free to withdraw at any time without penalty. If you withdraw, are dismissed from the study, or if your employment is terminated, we will retain data collected before that time, but delete any data collected in the interval between when we become aware of the withdrawal/dismissal and before we are able to remove the data collection equipment. If you withdraw from the study, or if your employment is terminated, you will be paid for the questionnaires you have completed up to that time. Withdrawal from this study will not adversely affect your employment status.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Participants at Virginia Polytechnic Institute and State University. You should know that this approval has been obtained and is valid for the dates listed at the bottom of this form.

IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. To conform to the laws and regulations of driving on public roadways.
2. To follow the experimental procedures as well as I can.
3. To inform the experimenters if I incur difficulties of any type.

X. Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I understand that I may withdraw at any time without penalty. I agree to abide by the rules of this project.

_______________________	_______________________	_______________
Participant's name (print)	*Signature*	Date
_______________________	_______________________	_______________
Experimenter's name (print)	*Signature*	Date

Should I have any questions about this research or its conduct, I may contact:

Richard Hanowski, *Principal Investigator* (540) 231-1513, rhanowski@vtti.vt.edu
Darrell Bowman, *Project Manager* (540) 231-1068, dbowman@vtti.vt.edu

If I should have any questions about the protection of human research participants regarding this study, I may contact:

Dr. David Moore,
Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects
Telephone: (540) 231-4991; Email: moored@vt.edu

Participants must be given a complete copy (or duplicate original) of the signed Informed Consent.

APPENDIX H: INFORMED CONSENT FORM FOR MOTORCOACH DRIVERS

VIRGINIA TECH

Informed Consent for Participants in Research Projects Involving Human Participants

Motorcoach Drivers

Title of Project: Onboard Monitoring System Field Operational Test

Investigators: Richard Hanowski, Darrell Bowman, and Rebecca Olson

I. Purpose of this Research/Project

The main purpose of this study is to collect up to 12 months of continuous video and vehicle sensor data from 250 commercial vehicles. In addition, we will also be accessing your CDL driving record from the time you obtained your CDL until the end of your participation time in this study. This is being done in order to understand driver behavior and driving patterns. Data from this study will be used in a confidential way to understand commercial vehicle driving. This Informed Consent Form is to explain your role in this study.

II. Procedures

If you agree to participate in this study, you will be asked to do the following:

1. Read and sign this Informed Consent Form.
2. Allow an experimenter to photocopy or make a digital copy of your valid Class-A with passenger endorsement or Class-B with passenger endorsement, commercial driver's license – this information will be used to access your CDL driving records from the time you obtained your CDL until the end of your participation time.
3. Allow an experimenter to take a digital photo of your face – this will be used to identify you as the correct participant when looking at the video data.
4. Drive an instrumented vehicle for up to 12 months on your normal route(s). The vehicle instrumentation includes videotaping you (driver's seat only) at all times when the vehicle is on and in motion. The vehicle instrumentation also includes collecting data from the bus such as how hard you brake, your speed, forward radar, etc.
5. Fill out a brief questionnaire once a month and participate in a verbal exit interview at the end of your participation.
6. Allow us to potentially use short (approximately 30 seconds) video clips of you performing various behaviors for research-related presentations.
7. Allow us to access your vehicle every 2 to 3 weeks in order to swap out the hard drive containing the data. This process will involve you meeting with a study experimenter at your carrier's local maintenance shop, parking lot, or fueling station. The experimenter will be monitoring the capacity of the hard drive and make arrangements to meet with you the next

time you are at the fleet location to swap out the hard drive. The entire hard drive swap process should take approximately five minutes.

8. You will be contacted at the end of this study to ask if you would be willing to release your video data for training and educational purposes. At that time, you will also be asked if we may contact you in the future regarding the data collected during this study.

For this study we will be collecting data from approximately 500 commercial-vehicle drivers like you. In addition to the continuous video and vehicle data described above, we will also ask you to fill out a brief questionnaire once a month. The starting day of data collection is determined by the date when you start driving an instrumented vehicle.

III. Risks and Discomforts

There are some risks and discomforts to which you may be exposed to in volunteering for this research. These risks include:

1. The risk of a crash associated with driving a commercial vehicle as you usually do.
2. The risk of filling out the questionnaires is minimal and similar to completing office paperwork.
3. Stress associated with being continuously recorded while driving (the video will show your face, a forward view, an over-the-shoulder view, side view, and your actions in response to the driving situation).
4. If you drive into an area where cameras are not allowed, including international border crossings, certain military and intelligence locations, and certain manufacturing facilities, there is a risk that you may be detained or arrested or that your vehicle may be impounded.
5. There is an additional risk not encountered in everyday driving. While you are driving the instrumented vehicle, cameras will record continuous video of you, your actions, and surrounding traffic. In the event of an accident, there is a risk that the video and vehicle parametric data could be obtained in conjunction with a government inquiry, or in litigation or dispute resolution. However, under normal circumstances your identity and the company you work for will be kept confidential.

The following precautions will be taken to ensure minimal risk to the participants:

1. You will be instructed to follow your company's safety protocol.
2. Your participation in (or withdrawal from) this study does not have any influence on your status as an employee with your current company. However, it should be made clear that while the OBMS will be installed in your vehicle per company policy, your participation in the current study only involves allowing VTTI to collect continuous video and sensor data while your vehicle is on and in motion.
3. All data collection equipment will be mounted such that, to the greatest extent possible, it will not pose a hazard in any foreseeable way. Larger equipment will be mounted away from the cab occupants and rigidly fastened to the cab structure.

IV. Benefits

No promise or guarantee of benefits is being made to encourage you to participate. Past experiences with similar studies, involving heavy-vehicle drivers, indicate that you may find the study interesting.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participating, your name and the company you work for will be separated from the data and replaced with a number. That is, your data will not be attached to your name, but rather to a number (e.g., Driver 001, Location A). It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

While you are driving the vehicle, a camera will continuously videotape your face and other areas from five different angles: forward roadway, face view, over-the-shoulder, right-side of vehicle, and left-side of vehicle. An example is shown below. All continuous video and other data from this study will be stored in a secured area at Virginia Tech. Access to the continuous digital video files will be under the supervision of the Principal Investigator and lead VTTI researchers involved in the project. All data will be encrypted at the time of data collection and will be decrypted only for approved analyses.

*Note: The drivers face has been blocked to protect their identity in the above image. The video collected during this study will show your face.

One set of data will be permanently housed at Virginia Tech under the supervision of the Virginia Tech Transportation Institute, the organization overseeing the data collection for the entire study. It is possible that, after data collection is complete one copy of study data will be transferred to the U.S. Department of Transportation and/or other secure locations as directed by the U.S. Department of Transportation or the Virginia Tech Transportation Institute for permanent storage and oversight.

Authorized project personnel, authorized employees of the research sponsors, and authorized VTTI and research sponsor subcontractors will have access to continuous study data that personally identifies you or that could be used to personally identify you. As explained below, other qualified research partners may be given limited access to your driver data, vehicle data, driving data, and additional crash data, solely for authorized research purposes and with the consent of an IRB. This limited access will be under the terms of a data sharing agreement or contract that, at a minimum, provides you with the same level of confidentiality and protection provided by this Consent Form. However, even these qualified researchers will not be permitted to copy raw study data that identifies you, or that could be used to identify you, or to remove it from the secure facilities in which it is stored without your consent.

It is expected that the data we capture throughout the course of the entire study, including that from all the approximately 500 participants, will be a valuable source of data on how drivers respond to certain situations and how the roadway and vehicle might be enhanced to improve driver safety. Researchers who study traffic congestion and traffic patterns may also find the data useful. Therefore, it is expected that there will be follow-on data analyses using all or part of the data for up to 30 years into the future. These follow-on analyses will be conducted by qualified researchers with IRB approval, as required by law, who may or may not be part of the original study team. In consenting to this study, you are consenting to future research uses of the information and videos we gather from you, consistent with the protections described above and elsewhere in this document.

If you are involved in a crash while participating in this study, the data collection equipment in your vehicle will likely capture the events leading up to the event. You are under NO LEGAL OBLIGATION to voluntarily mention the data collection equipment or your participation in this study at the time of a crash or traffic offense.

We will do everything we can to keep others from learning about your participation in the research. We may disclose information about you as required by law, in conjunction with a government inquiry, or in litigation or dispute resolution. You should understand that this informed consent does not prevent you or a member of your family from voluntarily releasing information about yourself or your involvement in this research.

This Informed Consent Form does not prevent the researchers from disclosing voluntarily matters such as child abuse, or subject’s threatened or actual harm to self or others. This could also include behaviors such as habitually driving under the influence of drugs or alcohol, allowing an unlicensed minor to drive the vehicle. If this type of behavior is observed, we reserve the right to remove you from the study and inform the appropriate authorities of what we have observed. In most cases, we will notify you first of the behaviors we have observed prior to removing you from the study or informing others of our observations. If you are removed from the study, your compensation will be prorated based on the time you have already spent as a participant in the study.

In addition, at the end of your participation time, you will be asked to sign an optional additional form asking for your permission to release your data for training and/or educational purposes. Your choice of whether or not to allow your data to be used in this manner will have no effect on your participation in this study or on your employment.

VI. Compensation

You will receive $100 as a sign-up bonus for agreeing to participate in this study. You will also receive $50 a month for every questionnaire that you fill out. Finally, you will receive a $300 bonus if you fill out all required questionnaires and participate in the study for the full 12 months. If you elect to withdraw from the study or if your employment is terminated, you will be compensated for the questionnaires you have completed up to that time.

VII. Freedom to Withdraw

Participation in this research is voluntary. You are free to withdraw at any time without penalty. If you withdraw, are dismissed from the study, or if your employment is terminated, we will retain data collected before that time, but delete any data collected in the interval between when we become aware of the withdrawal/dismissal and before we are able to remove the data collection equipment. If you withdraw from the study, or if your employment is terminated, you will be paid for the questionnaires you have completed up to that time. Withdrawal from this study will not adversely affect your employment status.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Participants at Virginia Polytechnic Institute and State University. You should know that this approval has been obtained and is valid for the dates listed at the bottom of this form.

IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

4. To conform to the laws and regulations of driving on public roadways.
5. To follow the experimental procedures as well as I can.
6. To inform the experimenters if I incur difficulties of any type.

X. Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I understand that I may withdraw at any time without penalty. I agree to abide by the rules of this project.

______________________________ ______________________________ ____________________

Participant's name (print)	*Signature*	Date
Experimenter's name (print)	*Signature*	Date

Should I have any questions about this research or its conduct, I may contact:

Richard Hanowski, *Principal Investigator*	(540) 231-1513, rhanowski@vtti.vt.edu
Darrell Bowman, *Project Manager*	(540) 231-1068, dbowman@vtti.vt.edu

If I should have any questions about the protection of human research participants regarding this study, I may contact:

Dr. David Moore,
Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects
Telephone: (540) 231-4991; Email: moored@vt.edu
Address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

Participants must be given a complete copy (or duplicate original) of the signed Informed Consent.

APPENDIX I: DEMOGRAPHIC QUESTIONNAIRE

Please answer each of the following questions.

1. What is your age? _________ years

2. Gender: □ Male □ Female

3. How tall are you? ____________ feet ____________ inches

4. How much do you weigh? ____________ pounds (lbs)

5. Have you ever been tested for sleep apnea? □ Yes □ No
    a. If you marked ‘Yes’, do you currently have sleep apnea? □ Yes □ No

6. Do you wear contact lenses? □ Yes □ No

7. Do you wear glasses at night when driving? □ Yes □ No

8. How long have you been working at this company? _______years _______months

9. How long have you had a **driver’s license (non-CDL)**? _______years _______months

10. How long have you had a **commercial driver’s license (CDL)**? _______years _______months

11. Is your commercial vehicle □ Company-owned □ Privately-owned

12. What type of CDL endorsement/restrictions do you have? **(Check all that apply)**

    □ Passenger (P)
    □ Tank (N)
    □ Tank and HazMat (X)
    □ Intrastate only (K)
    □ Double/triple trailer (T)
    □ HazMat (H)
    □ Other, please specify _____________________

13. Do you typically operate: **(Check only one)**

    □ Solo □ In a team or couple □ Slip seat

14. Have you ever used a system that provides real-time alerts while driving?

    □ Yes □ No **(Skip to question 18)**

15. How many different systems have you used in the past five years? _________________

16. Please indicate the company name and the period of use of the <u>last</u> system you used.

    Company name: ____

    Used from __________ (mm/yy) to __________ (mm/yy)

17. Please indicate how much you would agree with the following statement:

    In general, the alert systems that I used were useful in improving my driving safety.

□	□	□	□	□	□	□
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

18. How many employers have you had in the last five years (**including** your current employer)? ______

19. How many of these employers required you to have a CDL? __________

20. Did you attend a commercial vehicle driver training school? □ Yes □ No
    a. If you marked 'Yes', what was the duration of the training? _______weeks _______days

21. Do you have more than one employer? □ Yes □ No
    a. If you marked 'Yes', what other jobs do you currently work? _________________

22. What is your current marital status? **(check only one)**:

    □ Now married **(Skip to question 25)** □ Widowed □ Divorced □ Separated □ Never married

23. Are you currently living with a boyfriend/girlfriend or partner?

    □ Yes □ No **(Skip to question 25)**

24. Are you currently living in a registered domestic partnership or civil union?

    □ Yes □ No

25. How many dependents do you have (e.g., parents and/or children)? __________

26. What is your highest level of education?

□ Some high school or less
□ High school diploma
□ Some college
□ 2-year college degree/trade school
□ 4-year college degree
□ Master’s degree
□ Professional degree
□ Doctorate degree

27. Are you of Hispanic or Latino origin?

□ Yes □ No

28. What is your race? Please select one or more.

□ White
□ Black or African-American
□ Asian
□ Native Hawaiian or Other Pacific Islander
□ American Indian or Alaska Native

29. Is English your first language? □ Yes □ No

a. If you marked ‘No’, what is your first language? ________________________________

30. a. How many **moving violations** have you had in the **last 36** months: __________

b. How many of these **moving violations** were in the **last 12** months: __________

31. a. How many **vehicular crashes** have you been involved in during the **last 36** months: __________

b. How many of these crashes were considered '**your fault**': __________

32. a. How many **vehicular crashes** have you been involved in during the **last 12** months: __________

b. How many of these crashes were considered '**your fault**': __________

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APPENDIX J: POST-STUDY QUESTIONNAIRE FOR FEEDBACK GROUP

Thank you for your participation in this study. Your participation will help to determine the benefit of providing drivers of commercial vehicles feedback on their behavior. This feedback is expected to reduce the number of SCEs and to improve drivers' performance over time.

1. I think using the SmartDrive system has made drivers in my company more aware of unsafe driving behaviors.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

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2. I think using the SmartDrive system has increased my safety supervisor's concern for driving safety.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

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3. People who are **inside** the company and influence my behavior think that the SmartDrive system makes me a safer driver

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

4. People who are **outside** the company and influence my behavior think that the SmartDrive system makes me a safer driver

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

5. **Coaching** from my supervisor was effective in improving my driving safety.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

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6. Compared to warnings from the SmartDrive system, **coaching** from my safety supervisor was...

☐	☐	☐	☐	☐	☐	☐
Much Less Effective	Moderately Less Effective	Slightly Less Effective	Equally Effective	Slightly More Effective	Moderately More Effective	Much More Effective

Please provide any additional comments here if you wish to elaborate on your response.

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7. Compared to warnings from the SmartDrive system, **coaching** from my safety supervisor was:

	Much Less Effective	Moderately Less Effective	Slightly Less Effective	Equally Effective	Slightly More Effective	Moderately More Effective	Much More Effective
a) Hard braking	☐	☐	☐	☐	☐	☐	☐
b) Hard accelerating	☐	☐	☐	☐	☐	☐	☐
c) Swerve	☐	☐	☐	☐	☐	☐	☐
d) Speeding	☐	☐	☐	☐	☐	☐	☐

<u>General comments</u>

1. What did you **like** about the **warnings** of the SmartDrive system?

2. What did you **dislike** about the **warnings** of the SmartDrive system?

3. Did you find any of the information from the SmartDrive system hard to understand? If so, please describe.

4. Are there specific system improvements that you would recommend? If so, please describe.

APPENDIX K: POST-STUDY QUESTIONNAIRE FOR CONTROL GROUP

Thank you for your participation in this study. Your participation will help to determine the benefit of providing drivers of commercial vehicles feedback on their behavior. This feedback is expected to reduce the number of SCEs and to improve drivers' performance over time.

1. I think using the SmartDrive system has made drivers in my company more aware of unsafe driving behaviors.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

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2. I think using the SmartDrive system has increased my safety supervisor's concern for driving safety.

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

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3. People who are **inside** the company and influence my behavior think that the SmartDrive system makes me a safer driver

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

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4. People who are **outside** the company and influence my behavior think that the SmartDrive system makes me a safer driver

☐	☐	☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree

Please provide any additional comments here if you wish to elaborate on your response.

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APPENDIX L: TRAINING AND EDUCATION FORM

Video Release Form and Future Contact

Date

You recently participated in a driving study performed by the Virginia Tech Transportation Institute to evaluate driver behavior. This is one of the largest heavy-vehicle naturalistic driving studies of its kind and is generating wide interest from other transportation researchers. You may have been involved in a safety-related incident in the past 12 months. If so, we would appreciate it if you would grant to VTTI and the study's sponsors, the Federal Motor Carrier Safety Administration (FMCSA), permission to use those events in which you were involved for driver training and educational purposes. Please note that driving events shown will involve only events where there was a safety concern, not day-to-day normal driving. If you are willing to grant us permission, please choose which permissions you are willing to grant and then sign and date each of the following sections on the duplicate copy of this letter and return it to us. In addition, we would like to ask your permission to contact you in the future regarding data collected during this study. Keep in mind that you are under no obligation to grant these permissions – this is strictly voluntary, and you can take time to think about it if you need to. Agreeing or declining will have no impact on your employment, your participation or on your compensation for participation. We recommend that you keep this copy of the letter for your files.

Thank you for your assistance in this matter, and especially for your participation in this study.

Yours sincerely,

Rich Hanowski, Ph.D.
Principal Investigator
Virginia Tech Transportation Institute

I, ______________________________, have read this section in full. As indicated below for each case, I agree to release the Commonwealth of Virginia, Virginia Tech, and FMCSA, their officers, agents, and employees from any and all claims, demands, actions, liability, or suits at law or in equity, relating to or arising from the release or showing of any safety-related video recording, collected during February 2013 – March 2014, by the Virginia Tech Transportation Institute for use by VTTI, and FMCSA in the cases outlined below.

TRAINING AND EDUCATIONAL PURPOSES RELEASE

Release for driver's for training and educational purposes such as showing to students taking driver's education courses. Please check one of the selections below and then sign and date:

- ☐ I agree to allow video recordings to be released for training and educational purposes. I understand and accept the risk that these video recordings may end up on the Internet where they may be viewed by the general public, my current or future employers, the media, and my friends and family members.

- ☐ I do not agree to allow video recordings to be released for training and educational purposes.

FUTURE CONTACT

Release for future contact regarding the data collected during this study. Please check one of the selections below and then sign and date:

- ☐ I agree to allow VTTI researchers to contact me in the future regarding data collected during this study.

- ☐ I do not agree to allow VTTI researchers to contact me in the future regarding data collected during this study.

Signature: ____

Date: ____

Contact Information:

Address: ____

____

Phone Number: ____

ACKNOWLEDGEMENTS

This research was funded by the Federal Motor Carrier Safety Administration under Contract # DTMC75-09-H-00013. Dr. Martin Walker was the Task Order Manager and provided much appreciated advice and support throughout the project. The authors also thank Theresa Hallquist for her insight and support with this project.

The authors would also like to thank SmartDrive Systems for participating in this research and for providing the SmartRecorder units.

Additionally, the authors wish to thank the VTTI hardware staff (led by Andy Petersen), alongside Done Right Installation Group, who installed and serviced the instrumentation used in the data-gathering vehicles. We would also like to acknowledge the individuals who helped in the early stages of the project development, including Michael Mollenahuer, Myra Blanco, Kelly Stanley, Kelly Pitera, and Yiyun Peng.

This study could not have been conducted without the support of the safety-conscious trucking companies that participated. The authors thank these companies and their support staff at the fleet locations. Finally, this study could not have been conducted without the participation of the drivers. These nine companies and their drivers are dedicated to the trucking profession and have safety as a core value.

The data collection and analysis work plan was peer reviewed by three domain experts prior to the start of data collection, as was the final report. Details on this and complete copies of publications can be obtained by contacting these organizations and offices directly.

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